Visual Perception • Magnetorheological Fluids • Gravitropism • Secrets of Cell Growth

Space Research

Office of Biological and Physical Research

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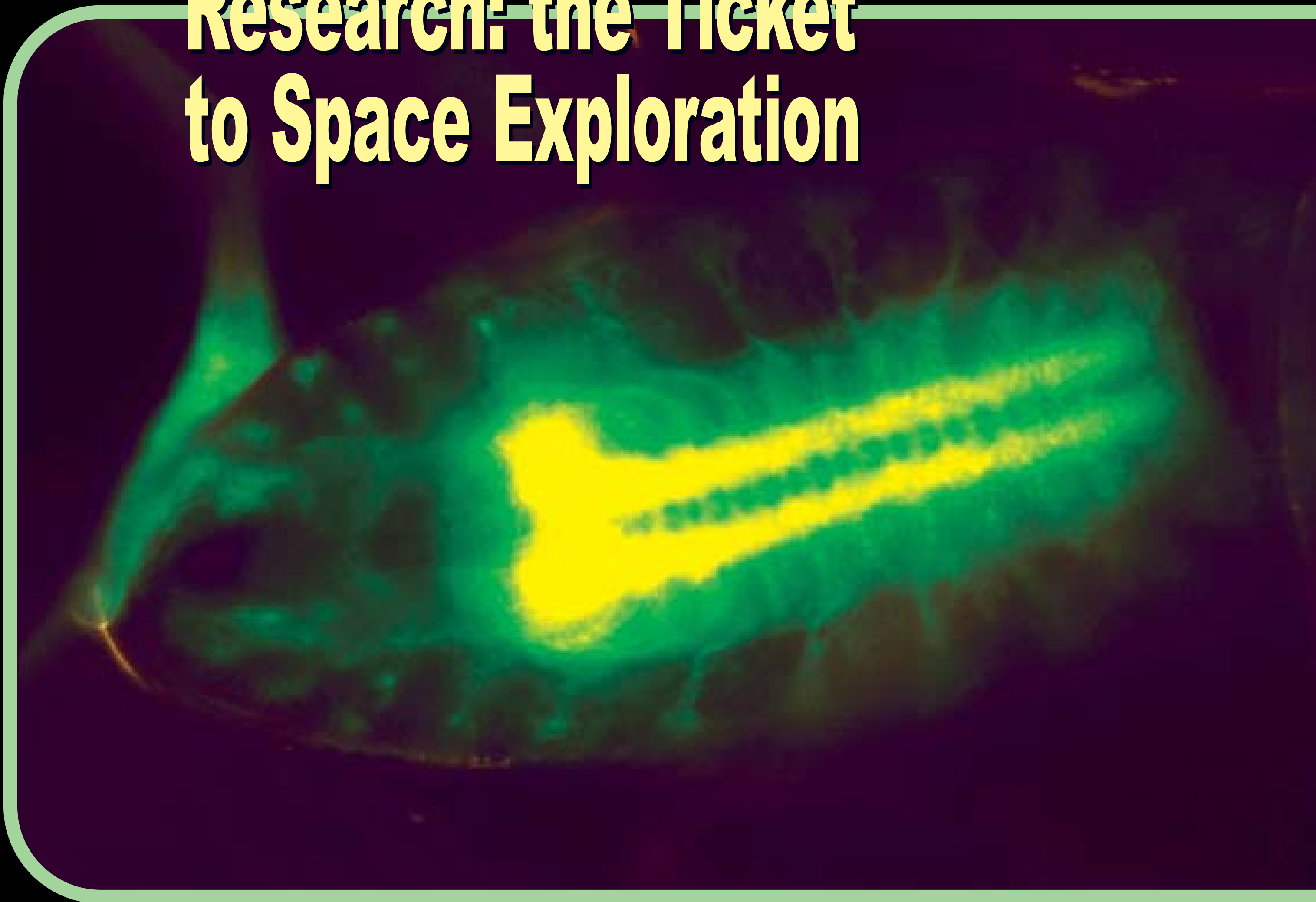
Research: the Ticket to Space Exploration



Profile: Clarence Sams

National Aeronautics and Space Administration

Letter From the Associate Administrator

Part of what makes the principal investigators and other scientists, the managers, and the support staff of the Office of Biological and Physical Research (OBPR) such a closely knit team is that we are all working toward the same NASA mission: "To understand and protect our home planet, to explore the universe and search for life, to inspire the next generation of explorers … as only NASA can."

In the June 2003 issue of *Space Research*, you read about how OBPR research supports the first part of that mission, understanding and protecting our home planet. Much of our research that helps make space travel as safe as possible for the crew may also be used on Earth to protect air, water, and food sources against natural or artificial contamination.

The feature in this issue describes how OBPR research supports the second part of the NASA mission, exploring the universe and searching for life. Our role in this endeavor is to explore the fundamental principles of physics, chemistry, and biology through research in the unique laboratory of space. OBPR is advancing toward this goal on many fronts, including the aforementioned sciences and research in the fields of medicine, materials science, combustion, fluid physics, crystallography, and an array of engineering areas. In this issue, we highlight advances toward finding more efficient means of powering spacecraft, studying the effects on the human body during long periods in space, improving medical tools for remote health monitoring and diagnosis, and developing defenses against the damage of cosmic radiation.

As NASA sends crewless explorer missions to Mars, the moons of Jupiter, and beyond, its spacecraft need special considerations for power. Fred Best and colleagues at the Center for Space Power (CSP) at Texas A&M University are changing the internal structure of silicon used in solar panels to improve the panels' efficiency. Scientists at the CSP are also studying what is required to prolong the life of lithium batteries used in the frigid temperatures of space.

As NASA works toward crewed missions once again transcending low Earth orbit, additional special considerations — such as how extended travel in space will affect humans and their living and working environments — must be addressed. James Thomas, a cardiologist at the Cleveland Clinic, has improved a three-dimensional echocardiogram to better monitor astronauts' hearts and to provide remote health diagnoses from Earth. Sharmila Bhattacharya, a researcher at NASA Ames Research Center, is studying the altered expression of genes in fruit flies that have been exposed to different gravitational forces. Information from multiple generations of these flies may help scientists understand what happens at the genetic level in response to altered gravity, and that information may some day be applied to helping humans adapt to microgravity.

Protecting humans, research experiments, and anything else inside a spacecraft from cosmic radiation is crucial. James Adams, a materials scientist at NASA Marshall Space Flight Center, is working with two consortia to find a lightweight material that can be used to build the structure of a spacecraft as well as protect its contents from radiation.

All of these researchers and many, many, others are working toward making it possible to send astronauts once more beyond low Earth orbit. As our knowledge increases, NASA will be better prepared to ensure that those astronauts not only survive but also flourish during their travels, so that new opportunities for scientific exploration can enrich their lives — and ours — and enable us to go beyond where we have been.

Mary Kicza
Associate Administrator
Office of Biological and Physical Research

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On the cover:
Scientists looked for changes to parts of this embryo's central nervous system (expressing green fluorescent protein [GFP]) due to the embryo's exposure to hypergravity in a centrifuge. (Contrast has been enhanced for publication purposes.) credit: Sharmila Bhattacharya

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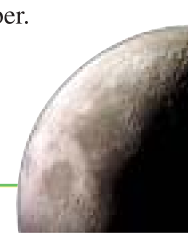
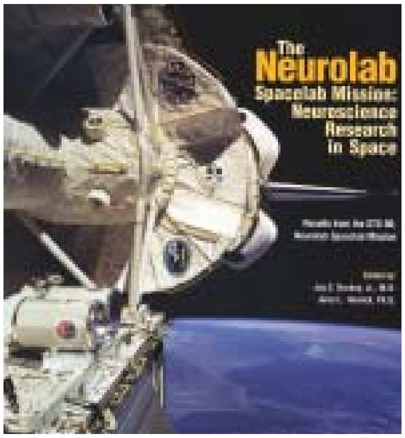


This Is Your Brain in Space



credit: NASA

The human brain and the rest of the nervous system make some surprising adjustments as astronauts adapt to microgravity, and NASA research on the matter has now been collected and published together. *The Neurolab Spacelab Mission: Neuroscience Research in Space, Results from the STS-90, Neurolab Spacelab Mission* (Jay C. Buckey Jr. and Jerry L. Homick, eds., NASA Lyndon B. Johnson Space Center, Houston, TX, 2002) documents the results of a 16-day space shuttle mission that was dedicated to studying the effects of microgravity on the brain and neurologic system.

The seven crewmembers of the space shuttle *Columbia* (STS-90), along with two alternate crewmembers on the ground, conducted 26 experiments during the June 1998 Neurolab mission. Experiments ranged from studies of gravity sensing to sensory connections made in the brain to actual astronaut perceptions of adapting to "weightlessness."

Jay Buckey, a physician and associate professor of medicine at Dartmouth College, Hanover, New Hampshire, flew aboard STS-90 as a payload specialist. He explains the advantage of publishing the results of these experiments together in one volume: "Taken together, these experiments offer a comprehensive view of how the [nervous] system strives to adapt to a novel environment such as weightlessness. By putting all the scientific reports into one volume, the connection between the experiments and their complementary nature become clear."

The book is divided into five areas — the balance system, sensory integration and navigation, nervous system development in weightlessness, blood pressure control, and circadian rhythms and sleep — and is designed to be accessible to the general public. However, it also contains detailed descriptions and references for scientists who want a more in-depth look at the research.

To order *The Neurolab Spacelab Mission: Neuroscience Research in Space, Results from the STS-90, Neurolab Spacelab Mission,* go to http://bookstore.gpo.gov and search for "neurolab."

Readership Survey Update

Results of the *Space Research* readership survey are still being tabulated. A summary of the results will be printed in the December issue of the magazine.

New Laurels to Principal Investigator Ketterle

credit: Burghard Hudig

Fundamental physics Principal Investigator Wolfgang Ketterle (right) receives the Medal of Merit of the State of Baden-Württemberg from Ministerpraesident Erwin Teufel (left) at a ceremony in Stuttgart, Germany.

Physicist Wolfgang Ketterle, professor of physics at the Massachusetts Institute of Technology (MIT) in Cambridge, and an Office of Biological and Physical Research principal investigator in the field of laser-cooled atomic physics, has received two awards from his native Germany for scientific research and other merits.

In April 2002, Ketterle received the Medal of Merit of the State of Baden-Württemberg. Ministerpraesident Erwin Teufel presented the award to Ketterle in a ceremony in Stuttgart, the state capital.

In November 2002 in a private ceremony, the German consul general to the New England States presented Ketterle with the Knight Commander's Cross (Badge and Star) of the Order of Merit of the Federal Republic of Germany, which is the highest award a civilian can receive from the German government. Ketterle was recognized for outstanding research accomplishments in the field of atomic physics. Says Ketterle, "I was thrilled to receive these recognitions."

Ketterle received a *diplom* (the equivalent of a master's degree) in physics from the Technical University of Munich, Germany, in 1982 and a doctorate in physics from the University of Munich in 1986. He became a research associate at MIT in 1990 after completing postdoctoral work in molecular spectroscopy at the Max-Planck Institute for Quantum Optics in Garching, Germany, and in combustion diagnostics in Heidelberg, Germany. In 1993, he joined the physics faculty at MIT.

CAREERS & the disABLED Honors NASA Researcher

CAREERS & the disABLED magazine has named NASA materials scientist Craig Moore a 2003 Employee of the Year for his professional achievements as well as advocacy efforts on behalf of people with disabilities in the workplace.

Moore, a computational chemist at Marshall Space Flight Center (MSFC) in Huntsville, Alabama, works in the materials science discipline of the Physical Sciences Research Division, supporting research into semiconductors and optical materials. The long-time NASA employee has been blind since shortly after birth. He was born prematurely and then was placed in an incubator, where he received excessive amounts of oxygen. The excess oxygen caused him to develop retinopathy, which rendered him completely without sight.

Moore attended mainstreamed classes in elementary and secondary school. From there, he went to North Dakota State University in Fargo and earned a bachelor's degree in chemistry in 1979. He received a doctorate in physical chemistry from the University of Cincinnati, Ohio, in 1986. Three years later, he joined NASA at MSFC.

CAREERS and the disABLED offers career guidance and recruitment support for disabled people who are professionals or college students. Each year, the publication presents awards to individuals who have demonstrated excellence in the workplace, advocacy efforts on behalf of people with disabilities in the workplace, and community involvement.

For more information about *CAREERS & the disABLED* magazine, see *http://www. eop.com/cd.html*. For more information about materials science research at MSFC, see *http://msad. msfc.nasa.gov/matsci/*.

credit: *CAREERS & the disABLED*

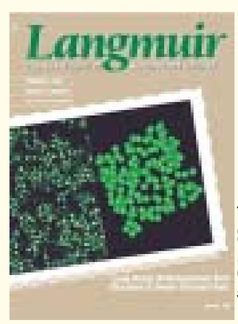
John Miller III, president and publisher of *CAREERS & the disABLED*, left, presents the magazine's Employee of the Year award to Craig Moore, a materials scientist at Marshall Space Flight Center who has been blind since birth.

Principal Investigators' Research on Covers of Two Journals

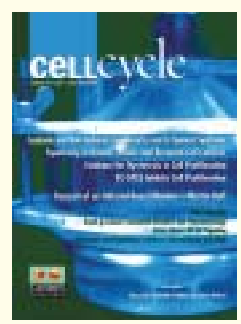
Science journals *Langmuir* and *Cell Cycle* recently featured the fluid physics research of Principal Investigator (PI) Michael Solomon of the University of Michigan in Ann Arbor and the cell culture research of PI Charles Helmstetter of the Florida Institute of Technology in Melbourne, respectively.

Solomon and his research team use a special imaging technique called laser scanning confocal microscopy to directly visualize and quantify the structural features of colloidal suspensions (systems of fine particles suspended in a fluid). Specifically, they study the suspensions that form gels as a result of attraction between colloid particles that are within short range of each other. The illustration on the cover of *Langmuir* shows a two-dimensional slice of a three-dimensional image of a colloidal particle gel on the left. The image on the right shows a two-dimensional projection of the three-dimensional coordinates of particles in the gel, as determined by quantitative image processing. For the complete article, see "Direct visualization of long-range heterogeneous structure in dense colloidal gels" by Priya Varadan and Michael Solomon (*Langmuir, 19*, 509–512, 2003).

Helmstetter developed a cell growth apparatus, shown on the cover of *Cell Cycle*, to evaluate the effects of long-term growth in space on the fundamental properties of cells. In the research described in the cover article, Helmstetter and his team compared the growth characteristics of synchronous (meaning all cells are at the same stage of the cell cycle — growth and division) human, mouse, and bacterial cell cultures and found that synchrony persisted in a similar fashion for all cells. Using their new culture apparatus, the researchers demonstrated that multicycle synchrony — the cells remain synchronous over multiple cycles of growth, which is essential for establishing the absence of significant growth imbalances induced by the synchronization procedure — is possible with these cell lines.



credit: Priya Varadan



For the complete article, see "Synchrony in human, mouse, and bacterial cell cultures: A comparison" (Charles E. Helmstetter, Maureen Thornton, Ana Romero, and K. Leigh Eward, *Cell Cycle, 2*(1), 42–45, 2003).

Research Carries Exploration to

Electrons bouncing out of silicon, sound waves capturing beating hearts, fruit flies spinning in a centrifuge at 1.5 times gravity, cosmic particles zooming near the speed of light — all hold the potential to contribute to research that will empower humans on a far-flung tour of space.

Care to take a spin through deep space? Using the wonder of human imagination, anyone can tour Mars or take the first steps on Ganymede. But to actually reach these destinations of the imagination and extend the reach of human life beyond Earth and its moon demands that scientists probe the biological and physical universe to a greater extent than ever before.

Although space researchers have learned how humans can survive in orbit for several months at a time, crews who tread the red soil of Mars or touch the icy moons of Jupiter will leave behind Earth's ample supply of air, water, heat, and food for many months or even years at a time. They will also travel beyond Earth's gravity and the protection against solar and cosmic radiation that Earth's magnetic field and atmosphere provide for longer than humans ever have before.

New tools and technologies must be developed to ensure the survival of these future explorers. Sustainable energy systems will be needed to power their cosmic journeys through deep space. The changes that their bodies undergo when most of Earth's gravitational pull is left behind will have to be monitored and interpreted. Countermeasures will be needed to slow or reverse any harmful changes occurring in bodily systems to keep crews healthy. Medical tools must be improved for remote monitoring of their health and diagnosis of injuries and ailments. And crewmembers will have to be protected against damage from solar and cosmic radiation.

The NASA Office of Biological and Physical Research (OBPR) currently supports projects that will meet these needs. This ongoing work will enable space researchers to take one more step beyond Earth's gravity and protection, toward the next leg in the human space journey.

Power Is Everything

Everything that happens in space travel — whether aboard a space station, in deep space, or on a Martian base — happens because power is available. Power gives crews air (by splitting water molecules), heat, and systems for navigation and communication. Crews on a planetary or lunar surface would also need to power vehicles for exploring terrain, tools for building habitats, and scientific instruments for conducting investigations. Optimizing power supplies for future exploration is top priority for Fred Best, director of the Center for Space Power (CSP) at Texas A&M University, College Station, Texas.

"Power is to a spacecraft what wings are to an aircraft," comments Best. "When we go to Pluto, when we go to Mars, when we go to Jupiter, thermal energy will keep the spacecraft alive. Once we move away from near Earth orbit, the spacecraft cools to tens of degrees above absolute zero and would be a rock without power, no matter what it's made of."

In space, the primary energy sources are the Sun and nuclear power, says Best. The International Space Station (ISS), for example, takes advantage of orbits relative to the Sun and can maintain power for years by converting sunlight into electrical energy through the use of panels called photovoltaic arrays. When the ISS slips behind Earth's shadow, nickel– hydrogen batteries take over. Even rechargeable batteries wear out, he says; they lose battery lifetime each time they are cycled.

Solar cells used on the ISS are made of a thin layer of silicon, which uses solar energy to bounce energized electrons out of the crystal lattice to generate electric current. The Sun emits an ample spectrum of energy, explains Best, but solar cells made of plain silicon (such as those on the ISS) react to only a certain part of that spectrum, thus limiting power output.

To improve the performance of the solar panels, CSP scientists are changing the internal structure of silicon by making what are called multiquantum wells. Best compares the wells to a screen mesh that can hold stones of many sizes. When the Sun shines on the mesh, "stones" (in the form of different wavelengths) collect, allowing the modified solar cells to gather and use more of the available spectrum. "The new wells will be efficient because they'll provide more power in the same size array," he says.

Multiquantum wells are more expensive to make than single-layer silicon, which means that for now, the technology is too costly to use on Earth. But in space, the trade-off with weight makes the technology a good option: Using high-efficiency solar cells on the ISS will require putting less mass into orbit.

The multiquantum wells would also suit a Martian visit. Because Mars is much farther from the

the Cosmos

Sun than Earth is, the sunlight is less intense, and the conversion efficiency of a multiquantum-well solar cell would be far greater than that of the current solar panels on the ISS.

Nightlife on Mars

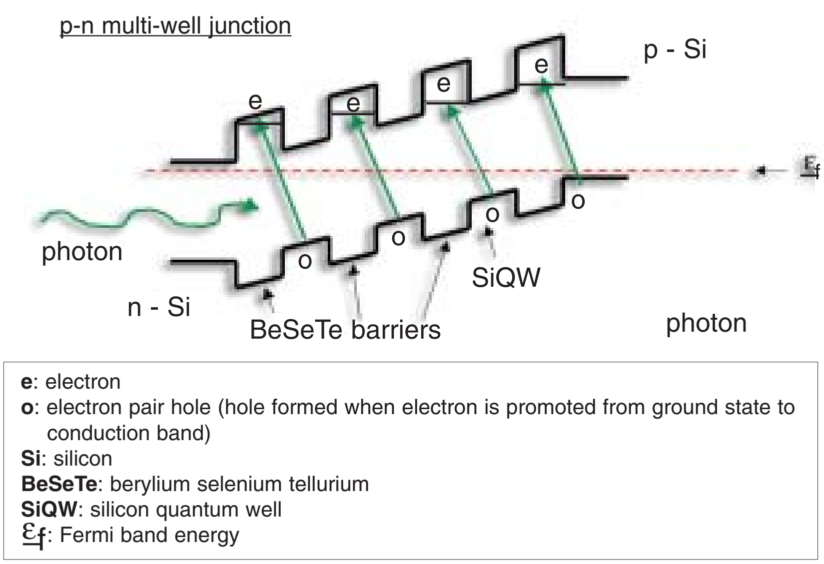
Efficient energy conversion is only one of many requirements for a stay on the Red Planet. After sunset, Martian visitors would need to switch to another energy source, such as battery power, like the ISS crew does when the Earth blocks the Sun's rays. Because weight would be a factor, the crew would need a battery with high energy density made of a lightweight material such as lithium.

On Earth, lithium-ion batteries are used in cell phones, laptops, and camcorders. But there is a big problem with using a lithium-ion battery — or any other battery — on Mars: Extreme cold limits storage capacity. "During the Martian night, it tends to get really cold, and you don't have a lot of power to spend to keep your batteries warm and your systems warm," warns Frank Little, associate director at CSP.

Cold, indeed. During Martian nights, the temperature dips below a frosty –63ºC (–81.4ºF), and low temperatures reduce the energy storage capacity of batteries and wear them out faster. Anyone who has tried to start a car after a string of subzero winter nights has learned that lesson. Little and his CSP colleagues are trying to dissect the chemical mechanisms of lithium-ion batteries and adapt them so they work over a wide range of temperatures.

Batteries work by electrochemistry: A flow of positive charge travels from a cathode to an anode. Standard alkaline batteries have a 1.5-volt potential between electrodes, whereas the inherent chemistry of lithium provides a 4-volt difference between anode and cathode. This means that for the same number of electrons, lithium-ion batteries give about three times the energy of alkaline batteries. The clincher is, electron flow in the lithium-ion battery works best at room temperature (21.11–23.88ºC [70–75ºF]), and lithium liquid electrolytes are thermodynamically unstable at the 4-volt potential. Little and colleagues found that decreasing the temperature of lithium-ion batteries dropped the storage capacity. At –30ºC (–22ºF), the storage capacity dwindled to a dismal 40 percent.

Quantum-Well Solar-Cell Design



credit: Wiley Kirk

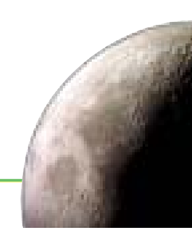
The silicon solar cells currently on the International Space Station (ISS) capture only part of the energy available in the Sun's spectrum. Scientists at the Center for Space Power at Texas A&M University (College Station, Texas) are improving the chemistry of the silicon wells to make multiquantum wells that capture a broader range of energy from the Sun. The cartoon shows the creation of electron-hole pairs in the silicon quantum wells. The arrows show where electrons jump from different areas of the quantum wells to conduction bands that will allow the silicon panel to capture a broad band of solar energies.

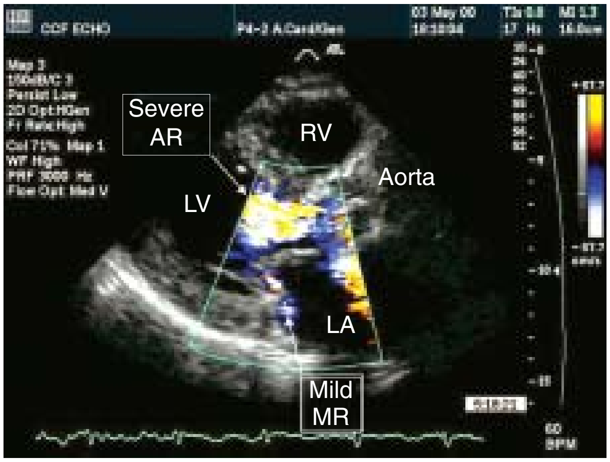
In addition, Little says that lithium-ion liquid electrolyte batteries form a solid layer of lithium-containing film at the anode that prevents further decomposition of electrolytes but removes lithium ions from the cell, thus reducing the overall storage capacity. This irreversible process also shortens battery life. "We've tried a number of things to reduce this layer formation," he says. "We're still working on that problem."

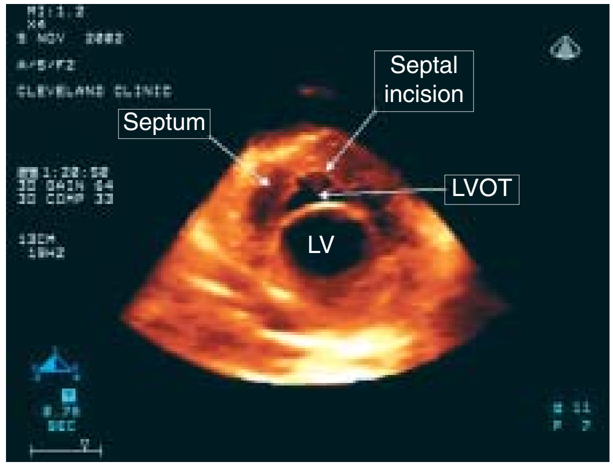
What Little and colleagues discover as they study the storage limitations of batteries could be used on lithium as well as other types of ion-insertion batteries. Any improvement in the energy storage capacity, Little explains, would be useful in consumer electronics because more energy could be packed into smaller, lighter batteries. Lightweight, energy-dense batteries would work even in the Arctic Circle, where the temperature on January nights dips to –30ºC (–22ºF). And commuters who live in frigid latitudes would be able to park their cars outside during winter and count on them starting right up in the morning.

Heavenly Bodies

Just as batteries aren't built to work in low temperatures, humans aren't designed to operate in low gravity. Efficient solar cells and hardy batteries go a long way toward creating the conditions for sustaining human life on one of Jupiter's moons or on Pluto, but scientists need to ready the human body for long-term







credit: Cleveland Clinic Foundation

Echocardiography uses sound waves to image the heart and other organs. Developing a compact version of this latest technology will improve the ease of monitoring crewmember health, a critical task during long spaceflights. NASA researchers are working to adapt the three-dimensional (3-D) echocardiogram for spaceflight; the two-dimensional (2-D) echocardiogram already in orbit on the ISS is effective but difficult to use with precision. A heart image from a 2-D (left) echocardiogram is of better quality than that from a 3-D (right) device, but the 3-D imaging procedure is more user-friendly. Once the image quality is improved and the device miniaturized, the advanced 3-D echocardiogram will be scheduled for spaceflight.

space stays as well. That means understanding how the body changes during long exposure to microgravity and variable gravity as well as developing countermeasures to support extended trips from Earth.

How will scientists study, monitor, and ultimately control the changes that sudden or prolonged exposure to different gravity environments may cause? The answers lie in methodically focusing on the effects of gravity, human by human, organ by organ, cell by cell, gene by gene.

One piece of this puzzle is being tackled by James Thomas, a cardiologist who is director of cardiovascular imaging and professor of medicine and biomedical engineering at the Cleveland Clinic Foundation in Ohio. Thomas is working to improve the understanding of how microgravity affects the heart by adapting a new piece of imaging technology for use in space. Thomas' new-and-improved version of a three-dimensional (3-D) echocardiogram may prove indispensable in studying the changes the heart undergoes in space and in remotely diagnosing heart and other health problems in space travelers.

Echocardiography images the heart using sound waves. Doctors use the visual record produced — called an echocardiogram — to diagnose heart problems such as heart attacks, leaky or too-tight valves, and abnormal wall thickening. The device can also be used to check the health of any organ (e.g., gall bladder, blood vessel, or kidney) that might need to be treated while astronauts are in space.

As with many organs and tissues, the heart changes dramatically in microgravity. For instance, immediately on insertion into orbit, without gravity to pool blood at the feet, about a liter of blood redistributes to the upper body. The heart floats out of the pericardial sac and enlarges; the face swells. Eventually, astronauts lose some blood volume through increased urine production and elimination.

Although these changes do reach equilibrium in space, they can cause problems when the crew returns to Earth, or perhaps some day lands on other planets, where gravity rules. Blood again pools in the legs, reducing the circulating blood volume, which can make astronauts dizzy and unsteady with dangerously low blood pressure. Also, the heart does not work as hard in space as on Earth because of the lack of gravity, and underused heart muscle could waste away over time. "When you come back down to the ground and stress the heart again, maybe it doesn't generate pressure the way it used to," says Thomas.

And the long-term effects of reduced gravity are unknown. What happens to an astronaut's heart after a year of travel, and how long will crews need to recover after landing on Mars before regaining enough strength to canvass the terrain on foot? Answering these questions may become a little easier after Thomas readies the 3-D echocardiogram for spaceflight.

Echocardiograms have already made their way into space. A two-dimensional (2-D) echocardiogram currently aboard the ISS is an important diagnostic tool for research applications as well as medical emergencies. For example, for investigative purposes, cardiac images can be taken with a 2-D echocardiogram on Earth, during spaceflight, and after landing to quantify heart structure and function.

The diagnostic capabilities of echocardiography are powerful, says Thomas, but 2-D echocardiograms are not user friendly. The heart is not stationary, which poses a problem for the person taking the image. The probe for a 2-D echocardiogram must be precisely oriented with anatomic markers of the heart so the resulting image can be properly interpreted. A probe placed improperly will distort the resulting image; chambers can look smaller and walls can look thicker, he explains.

The 3-D imaging device would be more suitable for space travel than the 2-D device because the probe for the updated machine is more forgiving of imaging position. Thus, Thomas, NASA's lead scientist for ultrasound technology, is adapting the 3-D echocardiogram for space.

Thomas faces several challenges. The images the 3-D echocardiogram produces are of lower resolution than those of the 2-D echocardiogram and are difficult to read. To improve image quality, Thomas needs to image and analyze hearts undergoing some sort of change so he and his team can optimize the technique well enough to analyze images before, during, and after spaceflight. Because valve-replacement surgery induces changes in the heart similar to the changes astronauts experience as they move from Earth into space, patients undergoing this procedure are perfect subjects for "before and after" observation. In both cases, the heart goes from a loaded to an unloaded condition. When valves are replaced, pumping becomes easier and the pressure often decreases, just as it does for an astronaut's heart in microgravity.

Thomas says it might be 10 years before 3-D echocardiograms are taken on a spin through the cosmos. Image quality must be improved and the device — currently the size of a small refrigerator — would need to be miniaturized to laptop size for a mission to another planet, because cargo weight and volume are critical.

Thomas is also developing wireless technology for the 3-D echocardiograms and conducting a study with the Department of Defense to adapt the device for battlefield telemedicine. Echocardiograms that are portable and easy to use would be well-suited for remote locations on Earth.

"We are developing the ground-based understanding to use this tool to get precise images of the heart pre- and postflight," says Thomas. "But the real pie-in-the sky vision, such as a mission to Mars, will require a very precise 3-D map of the whole body preflight against which to compare changes in flight."

Fly Genes Give Wings to Gravity Research

Echocardiography provides a map of an organ. But to peek inside the cells that make up those organs and chart gravity's influence at a molecular level, biologists plot a map of the genome.

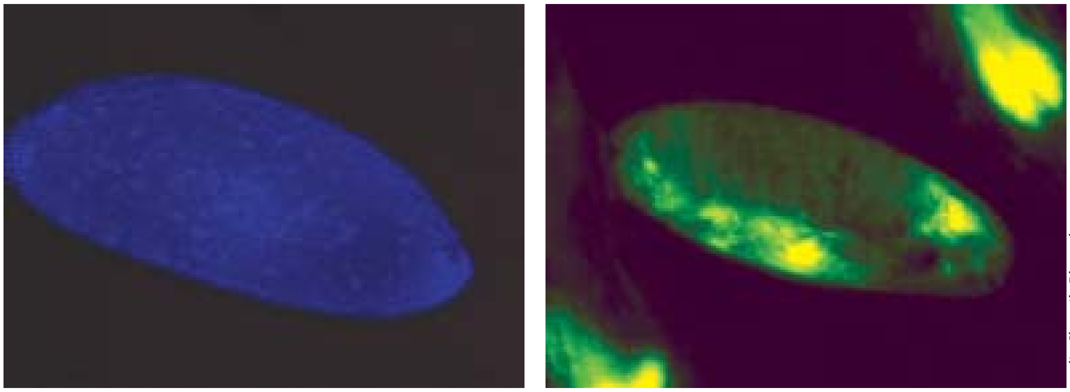
Genes command the building of proteins, which make up much of the tissue and carry out most of the functions of the human body. Understanding which genes respond to changes in gravity and cause corresponding changes in the body may help scientists design chemical countermeasures such as pharmaceuticals against the detrimental effects of long-term spaceflight.

As astronauts leave Earth's gravity environment for longer and longer periods, researchers have to ask, how will their genes respond? Will some genes be silenced over time? Will others stop sending orders to make a particular protein? Will still others be turned on and activated? When colonies are established on Mars, will the human body change over several generations in response to Martian gravity? What will happen when the great-great-great-grandchildren of the colonists visit Earth and feel this planet's strong gravitational pull for the first time?

One NASA researcher taking on these challenging questions is Sharmila Bhattacharya of NASA Ames Research Center, Moffett Field, California. But Bhattacharya isn't studying humans. Genetic studies to answer these questions require producing offspring over multiple generations in various gravity environments to follow how genes are affected — something that can't be done with people. So Bhattacharya is using a research model. Don't look now, but those pesky fruit flies circling your bananas are genetic cousins and may help biologists like Bhattacharya figure out why humans respond to gravity and the near lack of it the way we do.

Drosophila melanogaster, known as the fruit fly in common household lingo, reproduce quickly. These tiny (3-millimeter [0.12 inch]) critters have a life cycle of only 10 days from egg to mature adults. *Drosophila* are sexually mature approximately 12 hours after emerging from pupae, and they mate and lay eggs every day until death, making it easy for scientists to study multiple generations. This feature makes fruit flies as crucial to science as lab rats and a great choice for biologists studying how genes might change along the gravity continuum.

Because the genetic makeup of *Drosophila* is similar to that of humans, study of these pesky flies may shed light on several human responses to gravity. For example, *Drosophila* respond to circadian rhythms



credit: Sharmila Bhattacharya

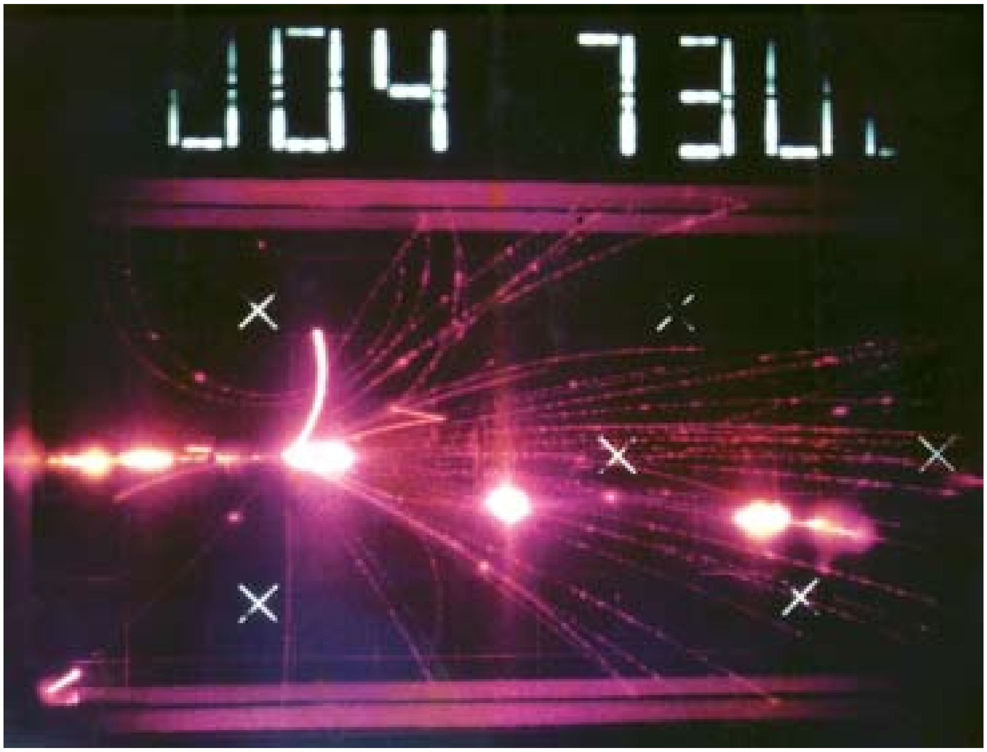
Drosophila melanogaster, commonly known as the fruit fly, has many genes in common with humans. Raising generations of flies on the space station will help scientists understand how life on Earth evolved in gravity and how to counteract some of the detrimental effects of spaceflight. To study these effects, Bhattacharya places embryos in a centrifuge, which exposes them to hypergravity, then looks for changes due to altered gravity conditions. Embryos are stained with chemical markers to help examine structural elements of the cells, such as the nuclei (left; stained blue with 4′6-diamidino-2-phenylindole dihydrochloride [DAPI dihydrochloride]), and tissues, such as parts of the central nervous system (right; expressing green fluorescent protein [GFP]).

A Bug's House

To prepare for her experiment in space, Sharmila Bhattacharya is working with a group in Canada to design an insect habitat suitable for breeding several generations of *Drosophila melanogaster*, the common fruit fly. On Earth, *Drosophila* thrive in kitchens, garbage dumps, and even in vials in a research lab. But providing an environment in which generations of flies can thrive during prolonged spaceflight is tricky.

Drosophila need a moist habitat at 60–80 percent relative humidity; oxygen, carbon dioxide, and nitrogen in concentrations similar to those in Earth's atmosphere; 12-hour light–dark cycles; and a carbohydrate-loaded menu of molasses, corn meal, and yeast. (They're fruit flies, after all; no high-protein Atkins diet would satisfy these critters.) The space habitat will also house a centrifuge, which will keep some flies in the same gravity as Earth (as controls), and a video camera to monitor all the flies' responses.

"Once the insect habitat is developed for space, we will have a very powerful tool that will answer many questions as to what gravity does," says Bhattacharya.



credit: Lawrence Berkeley National Laboratory

Researchers in the Space Radiation Shielding Program, sponsored by the Office of Biological and Physical Research, are using several accelerators to test potential radiation-shielding materials. Radiation can be measured using both electronic and visual detectors. This photo shows the violent results of a collision between two high-energy heavy ions. The detector was encased in a magnet, which bends positively charged particles down and negatively charged particles up. The red color is an artifact of argon gas used in the detector.

(light–dark cycles) like mammals do and need them for normal growth and development. "Flies are almost exactly like humans in this respect," says Bhattacharya. "They need light for their well-being and to set their body clock. Without light–dark cycles, they can survive and grow, but it's not ideal." Because sleep–wake cycles of astronauts change while in low Earth orbit and because these changes may affect their health and performance on cosmic trips, Bhattacharya's research could lend insight into how astronauts can cope with disturbed sleep cycles.

The flies also have an innate ability to align themselves with the gravity vector. Changes in the flies' normal behavior may give Bhattacharya meaningful insight into how humans sense gravity. "If you put *Drosophila* in a vial and gently shake the flies to the bottom, within seconds, they fly upwards or crawl up the sides of the glass," she says.

Bhattacharya is working toward a 90-day experiment on the ISS. In that amount of time, she should be able to study seven to nine generations of flies and track any changes in genes that respond to gravity. Although her ISS experiment (like many other life sciences flight experiments) has been put on hold because of the *Columbia* accident, she is studying the flies' responses to hypergravity using molecular tools and the specialized research centrifuge facilities at Ames Research Center.

In the day-to-day operations of biology labs, centrifuges are used to separate liquids of different densities or cells out of suspension. Because centrifuges increase gravitational forces on the samples, scientists interested in studying the gravity continuum use centrifuges in a very different way. In Bhattacharya's studies, *Drosophila* are placed in centrifuges and spun at different speeds, thus exposing the flies to different levels of gravity. Bhattacharya also varies the amount of time the flies spin.

A video camera attached to the centrifuge helps Bhattacharya watch for behavioral changes: Which flies are moving? Which are grooming? Which are doing nothing at all? These variations provide early clues that some of the flies respond to gravity differently. At certain times during the experiment, Bhattacharya removes flies and analyzes their ribonucleic acid (RNA), which is made from the deoxyribonucleic acid (DNA) code and eventually is translated into proteins.

Bhattacharya prescreens the flies she spins in the centrifuge, selecting some that have the mutations in the genes she wants to study. Because so many scientists use *Drosophila* as a research model, mutant flies (i.e., flies with intentionally altered genes) are readily available. "Luckily, in the fly field, there are tons of available mutant fly lines that we've been tapping into," she says.

By the time her ISS experiment is rescheduled, Bhattacharya hopes to have sorted out the genetic differences of *Drosophila* in response to gravitational changes. "We are seeing some interesting behavioral changes in the adult flies in response to increased gravitational forces," she says. "We are also seeing a reproducible set of genes whose alteration in expression corresponds to these behavioral changes. Therefore, we are doing detailed analyses of these genes in order to understand what the underlying molecular mechanisms are that correspond to the response to altered gravity environments."

To Protect and Serve

Every space traveler — even a fruit fly — needs to be protected from the destructive effects of cosmic and solar radiation. While cosmologists may, for example, study cosmic particles to locate black holes and dark matter, for NASA, cosmic and solar radiation pose major health hazards. Solar and cosmic radiation particles pass through spacesuits and the hulls of spacecrafts, producing particles that can damage tissue and mutate DNA. The longer a crew is exposed to radiation, the greater the risk to their health, both short and long term. On Earth, the planet's atmosphere and magnetic field help deflect these high-energy particles spewed out by the Sun and other sources, such as supernovas.

As space travelers move away from Earth, this protection wanes. Astronauts in low Earth orbit on

credit: Lawrence Berkeley National Laboratory

Particle accelerators have a long history of use in research. Edwin M. McMillan (center) was the co-winner of the 1951 Nobel Prize in chemistry. Cornelius A. Tobias (left) was the first to predict a biological effect produced by high-energy heavy charged particles in space. Here, along with Thomas Budinger, they verify that high-energy nitrogen ions impinging on their eyes produce effects similar to those reported by the Apollo astronauts.

the ISS, for example, still benefit to some degree from the protection of Earth's magnetic field but are above the protective effects of the atmosphere and thus are exposed to more radiation than are people on the ground. Interplanetary travelers heading for Mars and beyond would be battered with a wide range of solar and cosmic particles traveling at different speeds.

Because radiation damages DNA and causes mutations that can lead to cancer, protecting crewmembers from potential harm requires some combination of reducing time spent in space and shielding against the particles while on missions, such as the additional radiation shielding that NASA has installed in the ISS sleep station. ISS crewmembers could limit exposure by minimizing time in orbit. But a 6-month trip to Mars wouldn't offer that option.

The Radiation Shielding Materials Program, sponsored by the OBPR, aims to understand all of the effects of radiation on astronauts, quantify those effects as accurately as possible, and discover ways to protect spacecraft passengers. Achieving this goal requires understanding how radiation fields (the combination of energies and particle species in the radiation) change as they pass through matter. The high-energy particles in these radiation fields are difficult to stop, but they do lose energy and fragment as they pass though spacecraft, spacesuits, helmets, clothing, and ultimately, the human body — where the smallest particles can cause serious damage at the cellular level. Scientists need to test potential spacecraft structural and shielding materials against the combination of particles and energies in solar and cosmic radiation.

This is a good example of a problem that might look easy on paper but proves difficult in practice, says James Adams, program scientist for radiation shielding materials at Marshall Space Flight Center in Huntsville, Alabama. "This is very demanding. It's like saying 'go solve all the problems in nuclear physics,'" he says.

Adams works with two consortia formed for radiation protection. One uses particle accelerators to investigate the relevant nuclear physics and test the effectiveness of radiation shielding, and the other uses computer programs to calculate the effectiveness of shielding materials. One goal is to develop an accurate computational tool that can be used to reliably predict the radiation shielding effectiveness of materials. A second goal is to find a dual-purpose material: one that can be used to protect against as much radiation as possible yet is light enough to be used for the body of a spacecraft.

The ISS is made of aluminum because it's lightweight — a necessary consideration for spacecraft construction — but aluminum isn't the most effective shield against radiation, says Jack Miller of Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California. "Aluminum is used because of its strength-to-weight ratio, just as it is in airplanes. If radiation shielding were the main criterion, spacecraft would not be made out of aluminum." The best strategy to shield crewmembers from space radiation is to devise a shield that would slow and fragment the particles in the radiation field without

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Launching "Spacecraft Earth"

Slipping out of low Earth orbit into deep space for any length of time will expose crewmembers and their scientific payload to dangerous cosmic rays. Finding a suitable shielding material requires testing in the deep space radiation environment. The easiest way to gain access to this environment is on a balloon ride near one of the Earth's magnetic poles.

Earth's magnetic field deflects space radiation everywhere but at the poles, where the magnetic field lines bend outward from the Earth like water squirting straight up from a fountain, says James Adams of Marshall Space Flight Center.

The inability of Earth's magnetic field to deflect space radiation at the poles is a boon for inventive scientists in the NASA Physical Sciences Research Division. They have devised a way to mimic the radiation exposure of deep space by flying a balloon payload called Deep Space Test Bed near one of the Earth's poles, where space radiation pelts Earth much the same way that it batters a spacecraft in interplanetary space.

The idea works like this: A helium balloon would be launched from the Ross Ice Shelf near the south pole and "orbit" the pole, all the while exposed to space radiation. The "mission" would last 2 weeks or 1 month, depending on whether the balloon is allowed to make one revolution or two around the pole. Riding below the balloon would be a metal basketlike attachment (gondola) carrying various experiments, from radiation detectors to potential shielding materials.

Data from the Deep Space Test Bed will provide a test of the effectiveness of new candidate shielding materials in the real space radiation environment. Unlike accelerators, which provide data about one ion at one energy level, the space environment, explains Adams, is a mix of different elements over a wide range of energies. "The ultimate test will be to prove that potential shielding material provides the radiation protection in the real space environment that the computer programs say it provides," says Adams. "[At] under $1 million a flight, it's an inexpensive way to get frequent access to the deep space [radiation] environment."

A Mind's Eye for Safety

"The eyes are windows to the soul," they say. For NASA neuroscientist Leland "Lee" Stone, human eyes are more like windows to the brain, revealing what we actually perceive when we look at something.

A crewless Progress supply ship approached the Russian Space Station *Mir* for docking. Vassily Tsibliyev, a highly experienced cosmonaut aboard *Mir*, prepared to take remote control of the supply ship and guide it toward the space station. But a key piece of equipment was not working: *Mir*'s radar, which normally would tell Tsibliyev the supply ship's speed and distance. He thought he could "eyeball" the docking procedure by looking at the Progress through *Mir*'s window and using a display screen that showed an image of *Mir* taken from a camera on board the supply vessel.

Without radar, however, the cosmonaut could not tell that the approaching supply ship was moving too quickly until it was too late. The supply ship smacked into the space station, rupturing the hull of one of *Mir*'s modules and almost forcing the crew to evacuate.

The cosmonaut "misjudged what he saw. He misjudged the forward speed and distance" of the Progress, says Leland "Lee" Stone, a research psychologist in the Human Factors Research and Technology Division at NASA Ames Research Center, Moffett Field, California. "The radar would have given him that information. If you use purely visual information to determine how fast an object is approaching you, you only get accurate information when it is pretty close. The fatigue and stress of being in microgravity didn't help."

The June 25, 1997, mishap is one example of how visual perception can be wrong — how our eyes can fool us with optical illusions that could prove catastrophic, Stone says. "Astronauts and pilots can make mistakes, and these mistakes can have huge consequences," he adds. "Although not all these errors are related to vision and perception, some indeed are."

So Stone and Brent Beutter, another research psychologist at Ames, have developed a new method — oculometrics — in which they use eye movement measurements to determine what a person really perceives visually, even if that perception is incorrect. "We're trying to infer how well the human is performing from what their eyes are doing," says Stone.

Improving Flight Safety

Stone's research ultimately aims to combat potentially deadly sensory illusions by improving training methods and simulators not only for astronauts but also for pilots, air traffic controllers, and even airport security personnel. He also plans to help design better display devices for such users so "information that is important jumps out at them," he says.

Consider a space shuttle pilot, who must land a spacecraft by using a display superimposed on the window view of the runway. The display shows a symbol indicating where the shuttle is currently pointed, and the pilot uses a joystick to align it with another symbol that indicates which way the spacecraft should be pointed.

After days in microgravity, shuttle pilots are especially susceptible to sensory illusions. Stone has not yet used oculometrics to study how microgravity affects astronauts' perceptions, but spaceflight is known to cause abnormal eye movements and perceptual illusions. If a shuttle pilot tilts his or her head during landing, the shuttle seems to move in the opposite direction — a self-motion illusion that could be disastrous. "Because these illusions are associated with inappropriate eye movements, their eyes can jump away from the target, making them have a hiccup in trying to land the shuttle," Stone says.

Tracking the astronaut's eye movements during or right after landing could help astronauts "learn to recognize when they are experiencing illusions" and learn how to ignore them, Stone says. Eye tracking also could be used to train new astronauts, who practice shuttle landings on a simulator by aligning a cursor with a target superimposed on an image of a landing strip. "Let's say there is a pattern of eye movement typical of a novice astronaut just learning to land, and an eye movement typical of the expert astronaut who lands the shuttle as perfectly as possible," says Stone. "Can we use that eye movement information to train the astronaut to become an expert faster?"


credit: Rami Ersheid

Lee Stone tests a high-precision eye-tracking system he is installing on a 9.14-meter (30-foot) sled at the Vestibular Research Facility at Ames Research Center. Stone plans to study whether astronauts' eye motions coincide with their perceived direction of motion.

"Lee's work offers the potential of using measurements of eye movements to help give information back to the pilot about the world he or she perceives," says David Tomko, lead scientist for the Biomedical Research and Countermeasures Program, part of the NASA Office of Biological and Physical Research. "It has the potential to improve the performance of pilots, astronauts, air traffic controllers — anybody who works in a high-stress situation where they are required to make a whole lot of sense out of sometimes ambiguous visual cues."

NASA research psychologist Key Dismukes (right) and aerospace engineer Kurt Colvin (left) use a cockpit simulator at Ames Research Center. The simulator includes eye-tracking technology developed by NASA research psychologists Lee Stone and Brent Beutter. The simulator and eye tracker are being used to analyze eye movements and determine how splitting attention between the instrument panel and the outside world contributes to pilot error.

credit: Tom Trower

Measurements of the eye movements of effective airport security personnel as they scan X-ray images of baggage for guns and bombs could be used to train others. And knowing what pilots and air traffic controllers are doing with their eyes when they miss a crucial piece of information on a screen could improve the design of displays.

Tracking the Eyes

The link between eye movement and perception has been controversial, with debate centering on a kind of eye movement used by primates. Unlike most animals, which use only short, jerky eye movements called saccades to find moving objects, humans and other primates also can track a moving target with “smooth pursuit” eye movements in which the eyes rotate continuously. For example, space shuttle pilots use smooth-pursuit eye movements to line up the orbiter with the landing strip.

One school of thought holds that smooth-pursuit eye movement is merely a reflex that stems from light moving across the retina. The other view, supported by Stone’s experiments, is that many human eye movements are related to what we see, what we believe we see, and what we expect to see — and thus involve higher brain function.

For years, the only way to precisely track eye movements involved devices called eye coils, in which magnetic fields induced currents in contact lenses that contained wire coils. The current varied with the direction the eyes pointed, so eye movements could be measured electrically. But eye coils are expensive, invasive, and uncomfortable.

Over the past decade, Stone and colleagues have used video camera–based eye-tracking devices to precisely measure eye movements of human experiment subjects and mathematically convert the movements “into quantitative estimates of perception — what they actually see, what registers in their minds.”

To develop these estimates (also called predictive models), Stone asked experiment subjects to provide perception data by reporting what they saw while he used the eye tracker to record their eye-movement data. This information established a tight correlation between eye movements and visual perceptions and showed that oculometrics could be used to measure what subjects perceive on a display without interrupting their tasks the way that eye coils do. Stone also helped a manufacturer improve its eye-tracking device to measure eye movements as small as 0.1^{o} and to record such measurements 240 times per second.

During Stone’s experiments, human subjects sat in front of a computer monitor and were asked to perform visual tasks while dim infrared light (much like a bathroom heat lamp) was shined on their faces. A high-speed video camera and mirrors were arranged to capture infrared light reflected off the subjects’ corneas, allowing the camera to record eye movements. The idea was to induce optical illusions to determine whether eye movements reflect perception — regardless of whether those perceptions were right or wrong.

In a key experiment published in 1998 in *Vision Research*, a plaid pattern moved straight downward on a computer screen but was visible only through an oval-shaped window. When the oval was tipped to the left, its bottom pointed right, creating an optical illusion, so the experiment subjects reported that the pattern moved down and to the right, and their eyes moved that way, too. When the oval was tipped to the right, subjects reported the pattern moved down and to the left, and so did their eyes. Yet the pattern moved only straight down, showing that smooth -pursuit eye movements “follow the illusion and not the physical direction of motion on the screen,” Stone says.

In another experiment, a four-sided diamond shape made of simple lines appeared on the computer screen. It moved downward and slightly to the right or left. It could be viewed only through long vertical windows, also on the screen, so only the diamond’s four sides were seen — not its corners. When the windows were distinct, with four visible lines for edges, the subjects easily perceived the whole diamond and correctly determined its direction, and their eyes moved the same direction: down and slightly left or right. But when the windows were simply cutouts on the white screen, with no lines for edges, the subjects saw only four separate lines instead of the diamond shape, and their eyes moved straight down — the direction they wrongly perceived the lines were moving.

Stone could determine what the subjects perceived — a diamond or moving lines — by the directions their eyes moved. “If you have two possible interpretations of what is going on, the eye movement shows what interpretation you actually saw,” explains Stone, who published these findings in the journal *Perception* in 2000.

In a third study, subjects were asked which way a white dot moved on a black computer screen. The dot could move straight down, down and slightly right, or down and slightly left, but the subjects had only two choices: Did the dot move down and a bit right, or down and a bit left? The subjects’ eyes moved in the direction they reported the dot moved — down and to the right, or down and to the left — even when the dot moved straight down. Stone says that these studies established that smooth-pursuit eye movements could be measured to monitor how people visually perceive motion.

Research on the Move

Stone plans to determine whether astronauts in motion have eye movements that coincide with the actual direction of motion or the perceived direction of motion. As a first step, Stone and Stuart Smith of Trinity College in Dublin, Ireland, are conducting experiments using

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Getting to the Root of the Matter

Understanding how plants detect and respond to gravity will open numerous doors for controlling plant production in space and on Earth.

Have you ever bought a plant with every intention of planting it immediately but then got sidetracked — only to discover it days later lying on its side in the trunk of your car or in your dark basement? If the roots and shoots of that forgotten plant were escaping their packaging when you found it, then you probably noticed the phenomenon of gravitropism.

Even without the benefit of light, the leafy part of a plant will grow upward and the roots will curve to grow downward. This ability of a plant to reorient its growth with respect to gravitational force, known as gravitropism, is the subject of ongoing NASA research.

NASA investigator Michael Evans, professor emeritus at Ohio State University in Columbus, began his research career with an interest in how the hormone auxin affects plant growth. When a plant organ such as a root is laid on its side, auxin is thought to move to the lower side of the organ. In his studies of auxin action on root growth, Evans was looking for a way to get an unequal distribution of the hormone. To initiate auxin redistribution and observe how the hormone worked, Evans laid growing plants horizontally. "When we did that," says Evans, "we started seeing interesting growth effects, and pretty soon we were looking at that [behavior] in particular — how gravity was affecting the growth of the plant."

He continues, "[Our timing] was fortuitous in a way, because this was about the time NASA was becoming more interested in problems associated with growing plants in space as well as in fundamental research on how gravity affects the growth of plants." So, Evans applied for and received funding from NASA to study gravitropism. And he didn't even have to give up his earlier interest in plant hormones because auxin appears to play a role in how plants respond to gravity.

Going Down, Down, Down

How does a plant "know" that it has been laid sideways? "There is widespread agreement that the movement of special organelles in certain plant cells is the key step in informing the plant that it has been reoriented," explains Evans. These membrane-bound organelles are called amyloplasts. Amyloplasts, located in cells at the tip of the root (known as the root cap), contain dense granules of starch. Microscopic studies show that "when the root is growing straight down, these starch-filled organelles settle toward the bottom of the cell, a bit like marbles in a glass of water," says Evans. "They accumulate near the lowermost end of the cell, and if you turn the root 90 degrees onto its side, those starch-filled organelles are heavy enough that they resettle toward the 'new' lower side [of the cell]."

credit: Michael L. Evans

ROTATO allows researchers to study how plants sense and respond to gravity. A plant is placed at an angle other than vertical in the device's rotating stage, pictured here with a maize seedling attached. As the root begins the gravitropic response and the root tip begins to grow downward, the camera and associated software detect the curvature and signal the stage to rotate the plant so that the tip is returned to the original angle. Under these conditions, the root continues to curve indefinitely, thus permitting the study of its response to gravity over time.

Although most researchers agree about the function of amyloplasts, some questions remain about how the redistribution of these organelles toward the lower side of each cell leads to the redistribution of auxin toward the lower side of the root. The current model is that the settling of the amyloplasts toward the lower side of the cell somehow triggers the movement of auxin (also in the root cap) from cell to cell toward the lower side of the root. There, the auxin causes the cells to grow more slowly than the cells on the upper side, thereby causing the root to curve downward.

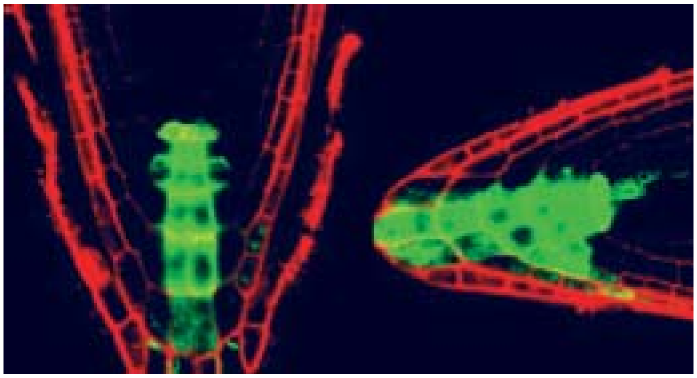
This fundamental explanation of root growth and curvature, known as the Cholodny–Went theory (after the two scientists who originally formulated this idea), has been around for decades. According to Evans, although the theory appears to adequately explain the phenomenon of gravitropism in general, it does not address its full complexities. Evans and his team wanted to know whether auxin did indeed move to the lower part of a root of a plant turned on its side, and if it did, how it affected the process of differential growth (i.e., slowing growth on one side of the root so that the root would curve).

ROTATO to the Rescue

To be able to study the effects of auxin on the cells in a growing root tip over time, Evans and his team needed to maintain a state of constant curving growth in the root. They had to find a way to keep the root from ever reaching a stable vertical orientation. ROTATO was their answer.

Evans and fellow researcher Hideo Ishikawa developed ROTATO, a device that consists of a highly precise, vertically rotating stage controlled by a motor that is regulated by a computer linked to a camera viewing the shape and orientation of the root. A plant is mounted on the stage, and

In these root tips of *Arabidopsis* (a small leafy cress), the green fluorescent protein is apparent in regions that have high auxin levels. In the vertically oriented, downward-pointing root (left), auxin is concentrated in the root tip. After the root is rotated away from vertical (right), auxin responds by extending toward the lower side of the cap.



credit: Courtesy of *Proceedings of the National Academy of Sciences, USA* (modified from Ottenschläger et al. (*Proceedings of the National Academy of Sciences of the United States of America, 100*, 2987–2991, 2002).

the camera is trained on the root tip, which is irradiated from behind with infrared. Infrared irradiation and an infrared camera are used to view the root because this type of irradiation does not influence root growth. The root tip is oriented at an angle other than vertical — for example, 90 degrees. As the root tip grows and "senses" that it is not pointing down, the downward curvature begins. The camera detects the resulting displacement of the root tip from its original angle and signals the computer to activate the motor to rotate the stage, returning the root tip to the original angle. In this way, the root continues to curve indefinitely, always trying to turn downward but never succeeding.

Rooting Out Answers

Historically, gravitropism researchers have believed that the only place a root can sense gravity is in the tip, partly because that's where the sedimenting amyloplasts are located. One of the first uses of ROTATO was to determine whether gravity sensing occurs elsewhere in the root. Researchers trained the camera farther back along the root and used ROTATO to keep that portion of the root at a constant angle. They observed that the region of the root behind the tip continued to curve despite the tip being allowed to reach a vertical orientation, thus indicating that areas along the root other than the tip can also sense gravity. "It turns out that gravity sensing back in that region is pretty weak compared to the gravity sensing at the tip — about 20 percent as strong as the gravity sensing at the tip," notes Evans, "but the fact is that it does occur."

This finding also fit nicely with the researchers' hypothesis that there are two sensors and two regions of curvature or "motors" that control root growth during gravitropism. But confirming that the two sensors exist led to additional questions: How does each sensor function? Are the two sensors connected? Are they completely different systems? What is the nature of the two motors? Is each controlled separately by one of the two sensors, or do the two systems overlap? Are both motors controlled by auxin, or just one? This last question brought Evans' research full circle, back to the effects of auxin on root growth.

Proof Glows Green

The team set out to determine whether and how auxin affects both regions, but to do that, Evans needed an easy method for tracking the presence of the hormone in the plant. He teamed up with a research group in Germany to develop transgenic plants in which a gene known to be "turned on" by auxin was linked to a gene that is responsible for producing a specific protein called green fluorescent protein. In such a plant, areas of green fluorescence in the root cells, observable by microscopy, would indicate the presence of auxin. Evans notes that the transgenic plant offers the advantage of not requiring the root to be killed or fixed to determine the presence or absence of auxin — researchers can observe auxin distribution in a root as it grows.

In the experiments, auxin behaved as expected. "When the root is growing straight down, the fluorescence appears uniformly in the tip of the root, and when the root is placed on its side, the fluorescence extends toward the bottom of the tip (on the lower side). This is one of the first real definitive tests of the popular idea that the major effect of gravity is to cause the hormone to move toward the bottom of the root tip," explains Evans. Although these results confirmed the longstanding model, surprises were in store for the researchers.

Still More Questions

Evans and his team moved on to the next step: determining whether auxin redistribution is responsible for triggering both motors or only one. Their data suggest that auxin controls only the motor located in the region farther from the root tip, known as the central elongation zone; this region is where the most rapid root growth occurs. The growth region just behind the root tip (known as the distal elongation zone) grows at a slower rate and does not appear to be controlled by auxin. This finding is unexpected, because gravity-induced auxin redistribution occurs in the root tip close to the distal elongation zone and some distance from the central elongation zone.

"The bottom line is that the hormone is controlling the motor that is farther back, not the one that's closest to the tip," says Evans. "And the idea is that once [auxin] gets redistributed in the tip [in response to gravity], it is sent back to the central elongation zone. The surprising thing is that in order to get there, it has to move through the growth region closest to the tip, but it doesn't seem to affect growth there."

Another clue that auxin does not control growth in the region just behind the tip is that curvature in that region does not result from asymmetric growth inhibition. "In other words," Evans explains, "in that region curvature results from a general acceleration of growth with the strongest acceleration along the top of the root. This is another indicator that auxin is not involved, because auxin produces curvature by asymmetrically slowing growth. So the growth patterns behind the two curvatures, the two motors, are very different."

Where the Root Will Lead

Using the sophisticated computer analysis that is available in ROTATO, fluorescent proteins, and several plant mutants with impaired gravitropic responses, Evans and colleagues hope to uncover more secrets of the nature and control of root growth in response to gravity.

Ultimately, Evans sees his research helping NASA to improve the long-term capabilities of growing plants in space. "The more effectively you understand the basic science, the more effectively you'll be able to design techniques for successfully growing plants in space," he says. "If we understand everything there is to know

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From Liquid to Solid to ...

Space research unveils another surprise in mysterious magnetorheological fluid.

Alice P. Gast already knew that magnetorheological (MR) fluids were complex when she first proposed studying them in space. She just didn't know how complex.

Gast, vice president of research and assistant provost at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, has spent years testing and modeling MR fluids, which turn from liquid to near-solid in the presence of a magnetic field. Her work has revealed intricate interactions not hinted at by the results of previous experiments.

Yet even Gast was astounded by the results of her InSPACE Microgravity Science Glovebox experiment aboard International Space Station (ISS) Expedition 6. In the low-gravity environment of orbit, MR fluids in a pulsed magnetic field evolved into what Gast, searching for a description, calls a "fluctuating dynamic sheet." The results, she says, were completely unexpected.

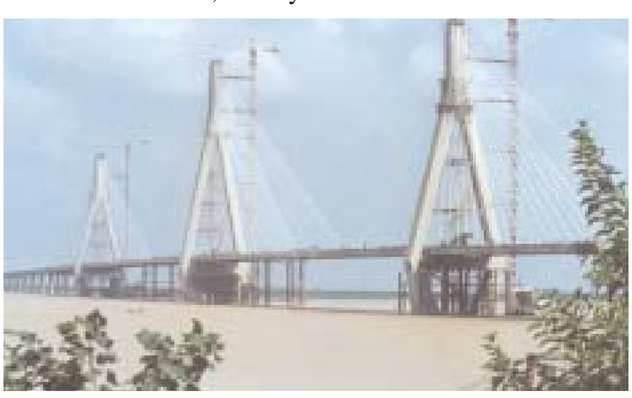
Emerging Uses

Those findings may prove important for MR fluids on Earth. Because of their ability to stiffen and relax, MR fluids make excellent energy dampers. They can switch between liquid and solid states within milliseconds, so they stiffen much faster than mechanical shock absorbers based on spring compression and on hydraulic friction. By varying the length of each magnetic pulse, engineers can adjust the average stiffness — and energy absorption — of the fluid to match almost any conditions.

MR fluids have already reached the market in bump-absorbing Cadillac shock absorbers and vibration-damping seats for long-distance truckers. The same vibration-absorbing technology stabilizes China's Dong Ting Lake Bridge and Japan's National Museum of Emerging Science during earthquakes and high winds. And Linde Lansing has replaced hard-to-turn mechanical steering linkages in its forklift systems with an electronic steering system that integrates MR fluids to provide tactile feedback to drivers.

MR fluid dampers help amputees walk with a more natural gait and keep long robotic arms from wavering. Ultimately, related technologies could provide physicians doing remote surgery with precise tactile feedback and act as valves in microfluidic lab-on-a-chip systems.

Before this trickle of commercial MR products turns into a flood, though, scientists need to know more about how MR fluids behave over time. Do MR fluids have a shelf life? Do they change after prolonged cycling? Can they be switched on with lower magnetic fields? Can their performance be improved? Gast hopes the insights into fundamental MR properties discovered aboard the ISS will help answer these and other questions.



credit: Lord Corp.

China's Dong Ting Lake Bridge outside Changsha, Hunan Province, uses MR fluid motion dampers to keep the cables that suspend the bridge from swaying in heavy winds. Space research provides important clues about the long-term stability of MR fluids in this and other applications.

Balance

For Gast, MR fluids were a natural extension of her research. Her research has long focused on surface interactions in colloids, which are liquid mixtures of particles fine enough to remain suspended for prolonged periods. "There is a delicate balance of interfacial forces [where particle and liquid meet] that keep the particles from settling out or forming beautiful crystals," Gast explains. "I was interested in how small changes in those forces have large effects on bulk properties."

In most colloids, she continues, the colloidal particles are evenly dispersed, and forces acting on them are isotropic (equal in all directions). MR fluids, however, provide unique insights into the ways directional forces such as magnetic fields affect structural transformations.

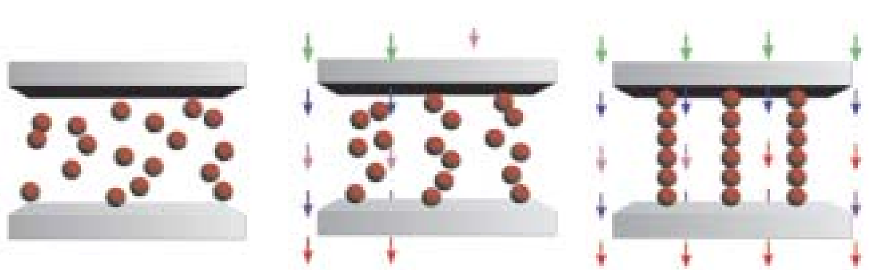
Those structural changes are nothing short of startling. In the absence of a magnetic field, the metal-based particles in MR fluids disperse like typical colloids. What makes them different is that they are paramagnetic; that is, a magnetic field will magnetize their metal components in much the same way that a pin is magnetized when rubbed with a magnet. This gives each magnetized particle north and south magnetic charges, making it dipolar.

"As soon as you turn on the field, the particles begin to interact in a dipole-to-dipole manner," says Gast. The attraction of opposite magnetic poles overcomes the delicate balance of forces that keeps particles dispersed and suspended. In concentrated MR fluids, particles line up pole to pole to form long columnar chains that branch and cross-link in three dimensions. The result is a fibrous, interpenetrating network of small particles that acts like large macromolecules.

What makes this network truly unique, though, is that it can support a load. "It goes from something with the consistency of honey to something like a gel," Gast explains. "You could use it as a damper, a mechanical transducer, or a clutch in a device."

Pulse

While at Stanford University in 1995, Gast and her student Joanne Promislow



credit: Lord Corporation

MR fluids contain paramagnetic particles that remain evenly dispersed like conventional colloids (left). When exposed to a magnetic field (center), however, they line up in dense, fibrous columns (right) that provide enough resistance to support a load.

became interested in what would happen to MR fluids as they aged. They figured they could prematurely ripen the fibrous structure of the network by rapidly cycling the particles between aggregated and relaxed states with the use of a pulsed magnetic field.

Rapid cycling adds a new twist to the equation. Applying a magnetic field freezes the MR particles in place; turning the field off lets the particles rearrange themselves to minimize the competing interactions between surface forces and the external magnetic field. "The magnetic force wants to stretch [the particles] out into long columns, while their surface tension wants to make them ball up into spheres to minimize their surface area," says Gast.

After several hours of cycling, the dense fibrous networks disappear. Instead, the particles aggregate into ellipsoidal structures. They look like a school of fish in water and no longer support a load. Fortunately, car shock absorbers do not form these equilibrium structures because they generate continuous fields only. But cycling could prove problematic in other applications if designs neglect to account for the effects of aging.

Laser Tweezers

Gast next turned her attention to the behavior of individual particles within structures created by continuous magnetic fields. Here, too, she encountered some mysterious behavior — but only after she learned how to manipulate individual particles in a chain.

Gast used optical traps, commonly known as laser tweezers. This technique uses the force created when light is scattered by a particle to trap the particle with one beam and move it with another. Although several milliwatts of laser power translate to only a few piconewtons, that is all the force it takes to move a submicron particle. Moving particles with laser tweezers also gave Gast a way to measure the forces that bind MR particles.

Gast found that it took about four times more force to pull apart the chains than her models predicted. She theorizes that each particle's local magnetic field helps stiffen the other particles in the chain. She also found that as she pulled chains apart, other particles often filled in the vacancies and helped stabilize the chain. As a result, chains failed more gracefully —more slowly, less catastrophically — than predicted.

Interestingly, Gast found a broader range of behavior than she expected when she varied the magnetic field. In strong fields, particles formed cross-linked fibers. In weak fields, they failed to maintain their structure. At intermediate strengths, though, they often showed elastic behavior. When stressed, they could reorganize themselves and increase their mechanical strength.

Space

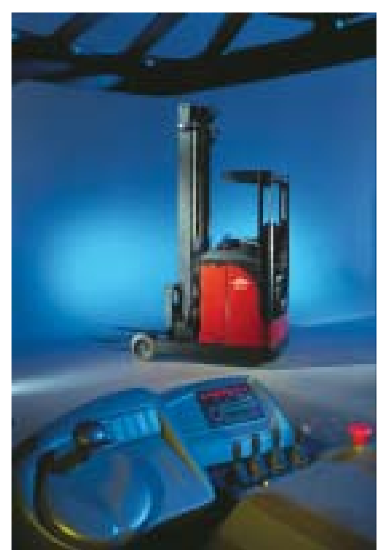
Gast's experiments helped elucidate some of the mysteries of MR fluids. But she still had a problem: MR particles and chains settle out of suspension over time.

The sedimentation rate of a chain is the same as that of an individual particle, she explains. Each particle has a certain mass and drag (that is, resistance to downward motion due to its length). Each time a particle joins the chain, it increases the chain's weight and drag by one particle, so chains fall at essentially the same rate as particles. But when two or more chains coalesce side by side, their mass increases while their length and drag stay the same, so they begin to sink.

Granted, says Gast, MR chains sink only a few microns per second. But that is fast relative to the nanoscale distances and piconewton forces of the chains themselves. Gast began to wonder whether eliminating those microns of motion by conducting experiments in space might unveil the ideal equilibrium structure of MR fluids in pulsed magnetic fields. That microstructure could offer important insights into the long-term properties of MR fluids.

The Space Shuttle *Endeavour* carried most of Gast's InSPACE hardware to the ISS on June 5, 2002. The samples, delivered 5 months later on STS-113, consisted of three primary and three spare Helmholtz electromagnetic coil units, each with a glass vial 1 square millimeter (0.0015 square inch) x 50 millimeters (1.97 inches) long. Each set of vials contained an MR fluid with a different particle size.

The entire assembly was placed under two cameras: one looking along the field



credit: Linde Lansing Förderertechnik AG

The Linde Lansing electronic forklift steering system is smaller and more reliable than the hydraulic system it replaced, but it did not provide any driver feedback. The ability of MR fluids to provide graduated resistance based on speed and direction solved the problem.

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Learning the Secrets of Cell Growth: Space Research Advances Current Culturing Technology

Ongoing space research on kidney cells is helping to refine and optimize cell culture experiments. The results may lead to the production of fully functioning, differentiated mammalian cells on Earth — an accomplishment previously possible only in microgravity.

Cells are amazing. Put a few in a flask with broth for food, keep them warm, come back later, and there has been a population explosion. It's like raising rabbits: Where once there were 2, there now are 2,000. However, using standard techniques, complex human or mammalian cells grown in culture do not look or behave like cells that have reproduced in bodily tissues.

Cells in a body (in vivo) that are altered by proteins such as hormones and enzymes to perform particular organ functions are called differentiated cells. Such organ-specific cells function normally only within their particular organ. Unfortunately, when removed from native tissue or grown outside the body (in vitro), specialized cells lose their differentiation and unique features.

With its associated microgravity, orbit spaceflight is a beneficial environment for growing differentiated cells, and NASA is working to replicate some of these advantages in ground-based technology through a three-way partnership. BioServe Space Technologies, a NASA Research Partnership Center at the University of Colorado in Boulder, is providing technological and engineering support to fly cell-growth experiments on space missions; Timothy Hammond, a nephrologist (kidney specialist) at Tulane University and the Veterans Affairs Medical Center, both in New Orleans, Louisiana, is designing and conducting fundamental studies of how cells function in microgravity; and StelSys, a biotechnology company in Baltimore, Maryland, is using the results of Hammond's space research to help develop commercially viable techniques for growing and using differentiated cells on Earth.

Growing Cell Potential

Why are differentiated cells so desirable? First and foremost, they can be used to test drug metabolism, efficacy or effectiveness, and interactions. Tests of new drugs must be performed on fully functioning tissue to be valid. Alternatives to animal testing are being sought for ethical as well as physiological reasons. As Hammond points out, animals do not always make good models for humans. "A rat is not a human; it has different metabolic enzymes. There are some cases where that has come back to haunt us, and the best example is thalidomide. Where thalidomide is perfectly safe in the animal species it was tested in, it's not safe for people. It was a drug used to control nausea in pregnant women, and it led to thousands of children with deformed arms and legs." Differentiated cells could reliably replace animals for drug testing in some situations.

Differentiated tissues are also useful for the fundamental study of cell genetics, particularly the determination of which genes are activated to produce specific hormones and other products of biochemical processes that are used commercially as drugs and chemicals. Additionally, from cells that grow and differentiate in vitro, researchers can learn about the mechanisms of differentiation itself. By understanding how, why, and when particular genes within cells are triggered, scientists may eventually produce cultured tissue that fully duplicates the functions of body tissue.

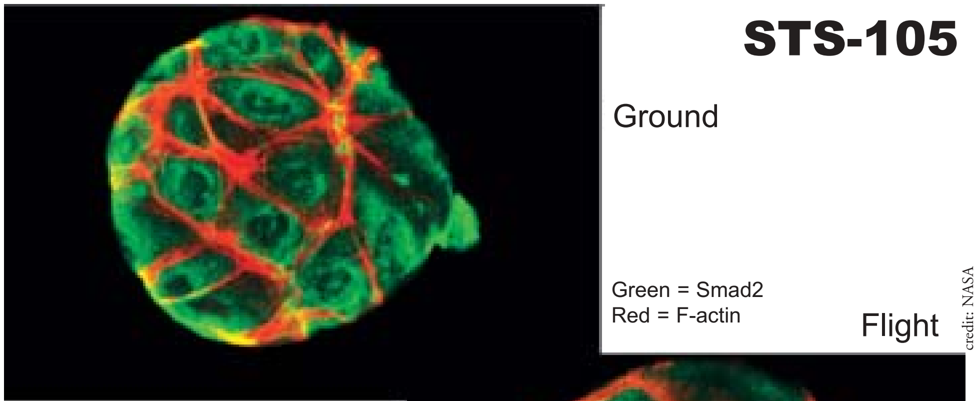
The NASA partnership seeks to advance all of these cell uses in general and to learn how to grow fully functional kidney and liver cells in particular. The ultimate goals are to harvest important proteins that the kidney produces and to develop a device to assist people with liver failure. One key to the partnership's eventual success will be research in a low-gravity environment.

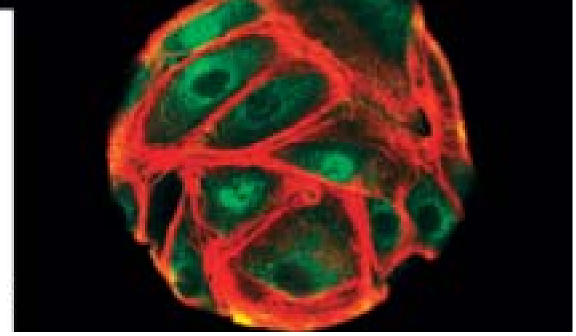
Escaping the Limiting Factor

Gravity is a limiting factor in growing and maintaining differentiated cells in vitro. In the body, cells grow naturally into fully functioning three-dimensional constructs. Cells grown in laboratories, however, behave differently. "All cells are relatively dense compared to the media they're grown in," explains Louis Stodieck, director of BioServe, "so they'll settle to the bottom. When they attach to the bottom of their culture environment, they'll typically flatten out and form a two-dimensional sheet of cells."

So, stirrers are used to keep the cells suspended, which creates another problem: shear, or the motion of cells against the growth medium and against each other. "Shear is dependent on the size of the particle [in this case, the cell], the density of the fluid it's in, and gravity," explains Hammond. "One of the best controls is to drop gravity out, because on Earth, with gravity present, you can't get the shear below a certain point and keep the particles off the bottom of the vessel." Cells grown in microgravity remain suspended in their liquid growth medium and naturally develop in three dimensions.

Flight research is an expensive proposition, and sample space remains premium real estate in the space environment. Even conducting relatively straightforward biotechnology experiments in space is a demanding endeavor. BioServe, having flown payloads aboard 23 missions (space shuttle, *Mir*, and the International Space Station), provides proven hardware and operational experience needed to enable these experiments. Understanding the unique opportunity before them, Hammond and his partners are making the most of the small batches of cells they have grown in orbit.





Principal Investigator Tim Hammond is examining how microgravity alters gene expression in differentiated or specialized kidney cells. These cells were dyed red for easy viewing. By adding fluorescent green tags to antibodies, Hammond can observe the cellular distribution of a particular protein — in this case, transcription factor Smad2. Smad2 is clustered in the nucleus of many cells grown in low Earth orbit (bottom) but appears mainly in the cytoplasm of cells grown on Earth (top).

Learning the Fundamentals

Hammond is studying the differentiated kidney cells grown and sustained during flight experiments to learn how to replicate their growth on the ground. "What you bring back from space," says Hammond, "is information; it's not a factory. So when we grow kidney cells or liver cells or whatever cells in space, what we're looking at is a pattern of changes in gene expression." In other words, Hammond wants to determine which genes initiate or stop protein production, which carry out cell functions, and when all of this takes place — then compare these data with data about cell function on Earth.

Hammond's kidney cell experiment that flew on shuttle mission STS-90, launched April 17, 1998, was the first spaceflight study that used human gene arrays (i.e., studies of which human genes are active). BioServe designed and manufactured the hardware that enabled Hammond to fly his next experiment on space shuttle mission STS-106, launched September 8, 2000. "We got back samples that generated beautiful gene arrays and were able to see which control proteins, or transcription factors, went into the nucleus of the cell to [activate the particular genes to start or stop producing proteins]," explains Hammond.

Hammond's most recent flight experiment, also supported by BioServe, was on space shuttle mission STS-112, launched October 7, 2002. In this experiment, he took the control proteins identified on STS-106, labeled them fluorescently, and captured their movements into the cells, identifying the activation point for some of their functions.

In addition, Hammond sent up a mixture of molecularly engineered yeast strains that differ from each other by one gene. Each of these genes was "knocked out" and replaced with an identifying "bar code." Recombining the strains creates a mixture that contains a deletion strain for every gene in the yeast chromosome. "Since they're all bar coded," explains Hammond, "you can mix them together, put a stress [such as an acid] on them, and grow them in space with that stress. The growth of each strain is dependent on the missing gene. So the results are going to give us the first definitive answer: which genes help and which hinder a cell's survival under microgravity conditions."

Yeast cells are valuable to the study of mammalian cells because the control proteins that give yeast its survival advantage or disadvantage are sufficiently similar to those in mammalian cells to be valuable for kidney research. Studying these control proteins in yeast is relatively simple, because the yeast genome is small. To do the same research on a mammalian cell is very difficult because of the complexity and size of mammalian genomes.

Hammond has proposed a research flight as part of flight 13-P on a Russian Progress (an automated, unpiloted spacecraft that brings supplies and fuel to the ISS) in November 2003, again supported with hardware provided by BioServe. He plans to send a mixture (which contains deletion strains that lack one [heterozygous] or both [homozygous] copies of a particular gene) of the same type of molecularly engineered yeast strains used on STS-112. It will give Hammond more complete information than the mixture flown on STS-112, because cells missing one of two copies of a vital gene will be less likely to die but will still be vulnerable to the stresses of microgravity.

From the Laboratory to the Real World

While Hammond is studying cell functions, StelSys is improving technology for growing cells on Earth by refining and optimizing processes used with a rotating bioreactor. Originally developed by NASA to mimic the effects of microgravity in ground-based experiments, the bioreactor creates a low-shear environment that allows cells to form in stable three-dimensional aggregates. Within these aggregates, cells develop as they would in native tissues. Dedifferentiated cells can regain most of their original functions when grown in the bioreactor, making them again viable for research. Although many researchers already cultivate cells in the bioreactor, the commercial potential of this technology has not been realized.

StelSys' objective, explains Nancy Cowger, chemical engineer and senior scientist, is to help solve real-world problems in the biomedical field. StelSys has three main goals for the commercial development of the bioreactor technology; two of these (a "metabolite generator" that produces valuable hormones and other biochemicals from liver and kidney cells, and a liver-assist device for patients with liver failure) are described in detail below. The third goal is to create a model of infectious

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Lessons Spun into a Cocoon

Students and teachers become pioneering "classroom principal investigators" exploring the effects of gravitational changes on the cabbage white butterfly.

The NASA Office of Biological and Physical Research (OBPR) has chalked an assignment on the board for students and teachers in the United States: to discover how butterflies respond to altered gravity. The data the classrooms collect may prove useful to NASA in planning closed ecosystems that astronauts might carry on long space voyages for raising vegetables and other food.

But not just any butterfly will do. Of particular interest is the brassica butterfly (*Pieris rapae*), the common cabbage white butterfly that flutters about summer vegetable gardens across North America. This butterfly has a symbiotic relationship with brassica plants, which include members of the mustard family (e.g., broccoli, cabbage, brussels sprout, turnip, and collard): The green caterpillar larvae eat the plants' leaves, and the adult butterflies pollinate the plants, allowing the plants to bear fruit.

credit: Wisconsin Fast Plants Program

The brassica butterfly (*Pieris rapae*), commonly known as the cabbage white butterfly and found in North American vegetable gardens, is the subject of experiments suggested by the NASA Office of Physical and Biological Research for students from kindergarten through grade 12 investigating the effects of altered gravity on living organisms. The butterfly has a symbiotic relationship with brassica plants (the family that includes broccoli and cauliflower): The larvae feed exclusively on the leaves, and the adults pollinate the same plants.

NASA researchers are interested in understanding how reducing or increasing gravity influences the behavior, development, and adaptation of organisms in general, and that's where the cabbage white butterfly comes in. Over the past 2 years, more than 100 classrooms have been involved in this kind of research.

The Brassica and Butterfly Education Project

NASA Fundamental Space Biology Outreach Program (FSBOP), based at Kennedy Space Center, Florida, tasked the Wisconsin Fast Plants Program at the University of Wisconsin at Madison to develop and implement the Brassica and Butterfly (B&B) Education Project.

The B&B project trains biology teachers to raise cabbage white butterflies along with an assortment of brassica plants in their classrooms and then simulate potential spaceflight experiments. Paul H. Williams at the Wisconsin Fast Plants Program has developed especially rapid cycling brassica plants (*Brassica rapa*, Rbr) that have an ultrashort life cycle of 35–45 days (seed to seed) and at full maturity reach only about 30.5 centimeters (12 inches) tall under ordinary fluorescent lights — perfect for classroom use. The butterfly's own life cycle from egg to reproducing adult is also 35–45 days.

The B&B project allows students from kindergarten through grade 12 to explore how two organisms can rely on each other for mutual survival. The NASA challenge to the students is to increase or decrease the gravitational acceleration experienced by developing butterflies, then note any physiological or ecological effects. Gravity plays an important role in the beginning of the cabbage butterfly's adulthood. Immediately after emerging from its chrysalis (cocoon), a butterfly hangs upside down for about 1 hour to let gravity pull hardening fluid to the tips of its wings. Without this essential step, the wings remain crumpled and the insect cannot fly.

The OBPR has been funding training workshops for teachers participating in the B&B project since November 2001. Growing plants and butterflies simultaneously isn't easy. Although the plants are fairly straightforward, maintaining 10–50 butterflies to document complete metamorphosis — egg, five separate larval instars (stages), pupa (chrysalis), and adult butterfly — is quite challenging. A 24-page project guide includes instructions on building three stage-specific butterfly containers along with recommendations for daily interaction and activity. Additional hardware for altering gravity (such as a turntable or a motor) is left for the students and teachers to devise. Schools also supply their own thermometers, video cameras, and other data-recording materials. In all altered-gravity experiments, students must compare the results of their experiment butterflies with those of a control group of butterflies grown under normal conditions.

NASA teacher-training workshops have been scheduled annually at the University of Wisconsin since 2001, and more than 70 teachers already have attended and walked away as "classroom principal investigators." These master teachers are equipped with the tools to help guide their students through learning the scientific method, including asking pertinent research questions. The teachers are required to train other teachers and to submit their research findings to Wisconsin Fast Plants Program Coordinator Coe Williams, who presents this information in a monthly newsletter that is distributed to other teachers and to NASA.

Reducing Gravity

Workshop ideas for altering gravity include record players, rotisserie motors, model rockets, and fans. But after the educators filter back to their homerooms, student innovation takes over.

For instance, Peggy White Henson's advanced-placement biology class at Moises Molina High School in inner-city Dallas, Texas, has sought to reproduce microgravity for the past 2 years by letting experiments free-fall from a mock drop tower. The purpose of the investigations was to assess the relative effect of change in velocity and of impulse (the acceleration of freefall and the impact of landing). The first year, Henson's class made "space shuttles" out of recycled materials — pairs of paper cups attached with fabric hook-and-loop fasteners, shaved packing foam filler for cushioning, and a cardboard spool as the craft's nose. Students tucked their experimental subjects (developing larvae and pupae) inside a "payload bay" (film canister) that was then placed inside the "space shuttle." To put the developing organisms in a state of freefall, each designer craft was dropped once from a height of about 2 meters (about 6.5 feet) onto a pillow.

The second year, the students placed 30 pupae in film canisters only and dropped them through a polyvinyl chloride (PVC) pipe for more control. Students dropped 10 canisters onto a pillow and 10 onto an overturned plastic tub and kept 10 as a control group (not dropped). After the experiment the first year, the butterflies exhibited changes in both development and behavior. After the second year's experiments, butterflies exhibited changes only in behavior. "Once the dropped organisms become butterflies," Henson explains, "we've noticed they do not interact or mate with one another."

Increasing Gravity

Lori Gillam, secondary science curriculum support specialist with the Anchorage School District in Alaska, aspired to put cabbage butterflies into a state of increased gravity. "We wanted to know what higher forces would do," Gillam explains.

credit: Lori Gillam

Secondary students in Anchorage, Alaska, work together to fill microcentrifuge tubes full of larvae and pupae, preparing the insects for takeoff.

Gillam contacted Elmendorf Air Force Base, Alaska, and coordinated with an F-15 fighter pilot to take 50 larvae and pupae loaded in microcentrifuge tubes on three routine training flights. The pilot stored the captive critters next to his helmet. On each 1.5-hour-long mission, the organisms endured a force of about 6–8 g. "There was no effect at all, except for one butterfly that emerged with crumpled wings several days after the flight," Gillam says.

For the first mission, students were not enthusiastic about taking the time to label each sample tube, but for the second mission, they understood the importance of organizing the data and how to prepare the containers for flight. The students reported that in several tubes, the larva had spun what appeared to be a hammock or a strap to secure itself to the inside wall. Gillam says. "We raised even more questions and look forward to flying more missions."

Gillam believes NASA's involvement makes the students much more interested in the science. "It's true science research rather than something made just for them," Gillam says. "This relevancy and direct link to cutting-edge NASA research makes the project much more enjoyable and meaningful for the students. They also understand that it is their research. They can change their questions, go back, revise — they are put at ease since nothing is set in stone."

The B&B project, for which an educator's guide is being produced, can be of interest to students from kindergarten through grade 12. Elementary school students can study the plants and insects simply as another life cycle; middle school students can study them as a broader ecosystem; high school students can peer into the unique character of the body hair and chemoreceptors distributed throughout the butterfly's body. Tom Dreschel, program manager for FSBOP, says, "All the science that the students are conducting correlates to research in fundamental space biology. The reason we do basic biology research in space is to look at how life has developed on Earth and determine how gravity has influenced that development. Most basic research has led to applications. [Data from the B&B project] may provide valuable information for using plants to keep people alive on extended flights later down the road."

Chris McLemore

For more information about the Wisconsin Fast Plants Program and the B&B project, check out the guides at http://www.fastplants.org/butterfly/. For information about brassica plants in space, see http://www.fastplants.org/fp_in_space/index.html. For more information about NASA's encouraging students to investigate the effects of altered gravity on the cabbage white butterfly, see http://www.fastplants.org/butterfly.pdf/Butterfly_Activity.pdf.

What's Happening on the International Space Station?

Despite a small crew, the Office of Biological and Physical Research continues scientific investigations on the International Space Station.

credit: NASA

Principal Investigator Richard Grugel examines the furnace inside the Microgravity Science Glovebox that is being used to conduct the Pore Formation and Mobility Investigation.

When Expedition 7 crewmembers Edward Lu and Yuri Malenchenko arrived on the International Space Station (ISS), they brought several new experiments for principal investigators (PIs) of the Office of Biological and Physical Research (OBPR). Below are brief descriptions of the latest OBPR experiments being conducted on the ISS.

PI Nick Kanas of the Veteran's Affairs Medical Center in San Francisco, California, is continuing an experiment to study the effects of crewmembers' cultural and language backgrounds on crew morale during long-duration space missions. The study will characterize changes over time in various interpersonal factors, including tension, cohesion, leadership roles, and the relationship between space crews and monitoring personnel on Earth. The long-range goal of Kanas' experiment is to improve the training and in-flight support of space crews. For more information about Kanas' study, see the article about his work in the Fall 2001 issue of *Space Research* ("The psychology of living and working in space," pages 11–13 and 25; also available at *http://spaceresearch.nasa. gov/general_info/spaceresearchnews. html*).

Several new physical science experiments also arrived on the ISS with Lu and Malenchenko. In an experiment titled Miscible Fluids in Microgravity–Isothermal, PI John Pojman of the University of Southern Mississippi in Hattiesburg is investigating whether temperature and concentration gradients in miscible fluids can induce stresses that cause convection. These stresses cannot be examined on Earth because the same gradients that cause the stresses also cause buoyant forces, which mask the stresses. In microgravity, however, buoyant forces are removed, and the stresses can be examined. Understanding the role that temperature and concentration gradients play in convection will allow the industrial processing of miscible polymer systems to be improved and could advance methods for processing materials in space.

PIs Richard Grugel of Marshall Space Flight Center (Huntsville, Alabama) and Fay Hua of Intel Corporation (Santa Clara, California) are investigating soldering in microgravity, which is particularly relevant to in-space fabrication and repair. In their study, In Space Soldering Investigation, Grugel and Hua will observe how the flow of solder is driven by surface tension and other forces that are normally masked by gravity. This experiment will help improve the understanding of lead-free solders and potentially improve in-space soldering methods.

Grugel also has another experiment running on the ISS. The Pore Formation and Mobility Investigation is being conducted inside a special furnace within the Microgravity Science Glovebox. In this experiment, samples of the transparent modeling material succinonitrile as well as succinonitrile–water mixtures will be melted, and the investigators will observe how bubbles form, move, and interact within the samples. The goal of this experiment is to better understand the formation and mobility of detrimental pores (bubbles) in metals and alloys during controlled directional solidification processing in space. For a more in-depth discussion of this experiment, see "Solidifying the future" in the June 2003 issue of *Space Research* (pages 16–17; also available at *http://spaceresearch.nasa.gov/general_info/spaceresearchnews.html*).

The Cellular Biotechnology Operations Support System (CBOSS) returned to the ISS with the Expedition 7 crew. Designed to provide a controlled environment in which researchers can grow three-dimensional tissue cultures in low Earth orbit that mimic living body tissue more closely than cultures grown on Earth, CBOSS is intended to be used until the Biotechnology Facility is installed on the ISS. On Expedition 7, CBOSS is being used for a fluid dynamics experiment (CBOSS-FDI). The PIs for this investigation are Joshua Zimmerberg of the National Institutes of Health (Bethesda, Maryland) and J. Milburn Jessup of Georgetown University (Washington, D.C.).

Growing healthy, functional three-dimensional tissues in space requires mixing cells and fluids completely during the various tissue culture procedures. CBOSS-FDI is designed to improve the potential return on investment of future Cellular Biotechnology Program investigations on board the ISS. It involves a series of experiments aimed at optimizing CBOSS fluid-mixing operations while contributing to the characterization of the CBOSS stationary bioreactor vessel (the Tissue Culture Module) in terms of fluid dynamics in microgravity. These experiments will validate the most efficient fluid-mixing techniques on orbit, which are essential to conducting cellular research in that environment, and will enhance the probability of success for future investigations.

For additional information about these experiments and others that have been conducted on the ISS, visit *http://spaceresearch.nasa.gov/research_projects/ros/ros.html*.

TECHNICAL MEETINGS

2004 Space Technology & Applications International Forum

Albuquerque, New Mexico
February 8–12, 2004
http://www.unm.edu/~isnps/staif/index.html

This year's Space Technology & Applications International Forum (STAIF 2004) has the theme "Creating the Future Together." Attendees will include representatives from government, academia, and the aerospace industry. The STAIF 2004 event will include five concurrent conferences on thermophysics in microgravity, space transportation, nuclear power and propulsion, space exploration, and space colonization.

2004 NASA Cell Science Conference

Palo Alto, California
February 26–28, 2004
http://slsd.jsc.nasa.gov/BSO/IWG/

Sponsored by the Cellular Biotechnology Program at Johnson Space Center, Houston, Texas, and the Fundamental Space Biology Program at Ames Research Center, Moffett Field, California, this year's conference aims to foster coordination and collaboration among the various NASA programs that use cell systems in basic and applied research, both in flight and on the ground. Activities will include scientific presentations, exhibits, a plenary lecture, and a business meeting to discuss the sponsoring programs and upcoming research opportunities.

EDUCATION MEETINGS

66th International Technology Education Association Annual Conference

Albuquerque, New Mexico
March 18–20, 2004
http://www.iteawww.org/D.html

This year's conference theme is "Teaching Decision Making in a Technological World." Attendees will have the opportunity to gather with other technology educators to share ideas, problems, and solutions. They will also have the chance to network at the conference's Technology Festival.

RESEARCH OPPORTUNITIES

http://research.hq.nasa.gov/code_u/code_u.cfm

Editor's Note: Starting in the September 2003 issue, coverage of research opportunities in **Meetings, Etc**. will change. NASA Research Announcements (NRAs) and other opportunities will be listed until their proposal due dates have passed. After that point, readers will be referred to web sites for additional information. A final listing for each NRA will include grant award information.

Research Opportunities in Physical Sciences

Fiscal year 2003 NRAs for the Physical Sciences Research (PSR) Division are as follows:

- **Fluid Physics:** NRA-02-OBPR-03-C proposals are due December 10, 2003.
- **Materials Science:** NRA-02-OBPR-03-E proposals are due October 31, 2003 (amended).

Additional information about these and the combustion science, fundamental physics, and biotechnology NRAs can be found at *http://research.hq.nasa.gov/code_u/open.cfm*.

In addition, selections are still being made for NRA-01-OBPR-08, the PSR Division's NRA for 2002. For more information about this and other announcements, see *http://research.hq.nasa.gov/code_u/nra/current/NRA-01-OBPR-08/index.html*.

Selections Made for Space Radiation Research

From 67 proposals received for NRA-02-OBPR-02, NASA has selected 28 researchers to receive grants totaling approximately $28 million to conduct ground-based research in space radiation biology and on space radiation–shielding materials. Each researcher will receive on average $1 million over a 4-year period. See *http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-02/index.html* for more details.

Combustion Science Grants Awarded

NASA has selected 21 researchers to receive grants totaling approximately $9.4 million to conduct ground-based microgravity combustion research. NRA-02-OBPR-03-B generated 79 proposals to conduct research for a maximum of 4 years. See *http://research.hq.nasa.gov/code_u/nra/current/NRA-02-OBPR-03/index.html* for more details.

PROGRAM RESOURCES

General Site

Office of Biological and Physical Research
http://spaceresearch.nasa.gov

- Latest biological and physical research news
- Research on the International Space Station
- Articles on research activities
- Space commercialization
- Educational resources

Descriptions of Funded Research Projects

Science Program Projects
http://research.hq.nasa.gov/taskbook.cfm

Commercial Projects
(also includes links to a description of the Commercial Space Center Program and other information)
http://spd.nasa.gov/sourcebook/index.html

Space Life Sciences Research Resources
(for literature searches)
http://spaceline.usuhs.mil/home/newsearch.html

Research Carries Exploration *continued from page 11*

credit: Lawrence Berkeley National Laboratory

Physicists can use particle accelerators to test the radiation transport properties of space suits and of potential shielding materials for spacecraft, as in this photo taken at the Loma Linda University proton synchrotron.

generating harmful secondary particles from the shielding.

Miller is head of the consortium on radiation transport measurements, which measures how radiation particles move through materials. His team uses particle accelerators to bombard likely shielding materials with particles traveling at speeds comparable to those of particles in space. The radiation consortium uses several accelerators. A proton accelerator at the Loma Linda University Medical Center in California mimics solar radiation. Most particles coming from the Sun are bare hydrogen nuclei, composed of one proton. Cosmic radiation is made up of mostly hydrogen nuclei with some helium and small amounts of nuclei of heavier elements. For tests of cosmic radiation, the consortium is using a synchotron at the new NASA Space Radiation Laboratory (NSRL) at the Department of Energy's Brookhaven National Laboratory in Upton, New York, which accelerates the nuclei of most elements. The group also collaborates internationally, using an accelerator in Japan to complement the NSRL findings.

Miller points out that in addition to research, particle accelerators have long been used to treat cancer. He says, "The most commonly used particles in charged-particle radiotherapy are protons and heavy ions" (typically carbon, which has six protons and six neutrons). Ions deposit most of their energy in a small volume, so they can be directed at a small area of the body, such as a tumor, with minimal harm to surrounding healthy tissue.

"This same property that makes ions useful in radiotherapy makes them a hazard in space," Miller explains. "You don't want them slamming into healthy cells in a healthy body. Our work relates to determining how effective different materials are in reducing the total radiation from ions in space." For a test, Miller places a potential shielding material in the accelerator. Detectors register the passage of a charged particle through a target, and the radiation into and out of the target is recorded and compared.

Because weight is always an issue in launching a vehicle from Earth, Miller and the consortium are testing lightweight materials that might do double duty for spacecraft construction and radiation protection. A promising candidate is polyethylene, a lightweight type of plastic. For use in spacecraft, polyethylene slabs could line the interior of the structure. This concept has already been implemented in the ISS living quarters at the initiative of Francis Cucinotta, radiation health officer at NASA Johnson Space Center.

Polyethylene is made of carbon and hydrogen. Hydrogen is an effective shield, explains Miller, because it slows and even stops charged particles but only rarely breaks them up, which would create secondary particles traveling at the same speed but with more penetrating power. Accelerator tests have shown that polyethylene is twice as effective as aluminum as a radiation shield.

With Co-PIs Cary Zeitlin and Lawrence Heilbronn, also of LBNL, Miller is testing material to protect crewmembers during stays on a moon or another planet, perhaps the hostile surface of Mars. One idea proposed by John Wilson and other scientists at NASA Langley Research Center in Hampton, Virginia, is to use Martian soil as a radiation shield. "Astronauts will have several options," says Miller. "They can dig themselves into [the] Martian surface, put down inflatable or light material, and shovel regolith (Martian soil) over the top. Or, they could use materials in combination with Martian soil to make bricks and build a shelter which would give protection against radiation and also provide some thermal insulation." These bricks, whimsically dubbed "Mars bars," have been fabricated at Langley Research Center using simulated Martian soil, tested at accelerators, and found to have radiation shielding properties.

Cracking the Code

"Since different particles have different biological effects, to understand what's going on biologically and to shield from it, you have to be able to describe physically what's going on with all these particles," says Larry Townsend, a nuclear physics professor at University of Tennessee, Knoxville, who heads the consortium to develop nuclear interaction models.

Because the space environment contains such a large mix of particles, testing all combinations on all candidate materials in accelerators is not possible, and that's where the consortium on computer codes comes in. Using computers to test model collisions can describe how radiation particles move through various materials and predict what percentage of which particles will be stopped, slowed, or scattered by the atoms in those materials.

To develop the computer models, Townsend must start with some solid data. His group uses experimental results from Miller's accelerator tests. Miller's group measures yields — that is, the type and number of secondary particles produced in a collision. Townsend incorporates the data in his transport code, which is a computer code that predicts how radiation travels through materials and how fields are changed by these collisions. He also tests some of his models' predictions against the results of the accelerator tests.

The models even allow Townsend to see how several kinds of materials might work together to stop particles. "With this information, you can pick out the optimum set of material types, thickness, and composition to minimize the radiation field that comes out the other side," says Townsend. "It's like layering clothes for protection from the cold."

The work of Townsend and Miller is painstaking. It may take the two radiation consortia years to find the perfect combination of materials for each craft, habitat, and mission, just as it may take years for all the other scientists working on future explorations to find the answers they need to develop new technologies. But as the scientists work out the nitty-gritty details of these problems, they also have in their mind's eye the voyages that their research will make possible.

"I simply think that it's our destiny to go into space," says Miller. "Plenty of smart people — many of them friends and colleagues — think that manned missions are a waste of money, that you can learn more for less with unmanned missions. I don't try to argue with them, because I think that framing the argument as a cost–benefit analysis is missing the point. Humans going into space is worthwhile for its own sake."

And when humans are ready to go beyond near Earth space, beyond Earth's moon, what should the goal of the first mission be?

"That's easy," Miller replies. "Mars. Humans walking on the surface of Mars. Even if they don't find a damned thing."

Jeanne Erdmann

NASA scientists are also developing nonchemical sources of power called spinning flywheels. For more information about flywheels, read "From child's toy to ISS: Flywheels hold the power" in the December 2002 issue of *Space Research* (pages 18, 19, and 26; read it online at *http://spaceresearch.nasa.gov/spaceresearchnews.html*).

For additional information about the Center for Space Power, visit the center's web site at *http://engineer.tamu.edu/tees/CSP/*.

To learn more about the adaptation of three-dimensional echocardiograms for space, read "Extraterrestrial house call" at *http://www.clevelandclinic.org/heartcenter/pub/history/future/nasafeature.htm*.

To learn more about *Drosophila* research, see *http://lifesci.arc.nasa.gov/CGBR/insect_habitat.html* and *http://ceolas.org/VL/fly/intro.html*.

For additional information about radiation transport, see *http://srhp.jsc.nasa.gov/*; to learn about NASA Space Radiation Laboratory, see *http://www.bnl.gov/medical/NASA/NASA-home% 20frame.htm*. Also see Jack Miller's article, "Proton and heavy ion accelerator facilities" (*Gravitational and Space Biology Bulletin*, 16, 1–9, 2003).

Eye for Safety *continued from page 13*

an eye tracker on a sled that floats on air bearings. "The sled will enable people to move in precise, repeatable ways," he says. "I can measure how well they perceive what direction they move in. Then I want to learn how their eye movements relate to the direction they perceive they move. I want to determine whether or not you can use eye movements to detect and measure self-motion illusions" that influence how astronauts and pilots control their vehicles.

Together with Elizabeth Wenzel and Randy Begault, auditory experts at Ames, Stone also wants to determine whether people's eye movements reveal something about how they locate and follow sounds as well as sights. He wonders, "As air traffic controllers listen to all the airplanes under their responsibility, would it help them if where they hear the sound coming from corresponds to where the planes are?"

In the long run, Stone envisions intelligent hands-off displays and controls that operate by inferring the intent of the user from his or her eye movements. Spaceflight mission controllers or air traffic controllers might be able to see one part of a display screen in greater detail solely by blinking or staring at the feature of interest. But before eye movements are used to control such sensitive activities, more research is needed to distinguish reflexive eye movements from willful ones. Otherwise, Stone warns, "it could be dangerous to control things with your eyes."

Lee J. Siegel

More information about Stone's research can be found at *http://vision.arc.nasa.gov/*; click on Selected Projects, then Eye Movements Metrics of Human Motion Perception and Search. Also see R. J. Krauzlis and L. S. Stone, "Tracking with the mind's eye" (Trends in Neurosciences, 22, 544–550, 1999). Studies mentioned in the article are B. R. Beutter and L. S. Stone, "Human motion perception and smooth eye movements show similar directional biases for elongated apertures" (*Vision Research*, 38, 1273–1286, 1998) and L. S. Stone, B. R. Beutter, and J. Lorenceau, "Visual motion integration for perception and pursuit" (*Perception*, 29, 771–787, 2000).

Getting to the Root *continued from page 15*

about how plants detect and respond to gravity, we're going to understand an awful lot about how they detect and respond to the environment in general." And that understanding will open a lot of doors for improving crop productivity on Earth and for successfully growing plants in space.

Julie K. Poudrier

Evans' research on auxin and green fluorescent protein was done in collaboration with the research group of Klaus Palme, Institut für Biologie II, Universität Freiburg, D-79014 Freiburg, Germany.

For additional information about Evans' research, visit *http://www.biosci.ohio-state.edu/~plantbio/Faculty/evans.htm* or *http://www.plantphys.net/article.php?ch=19&id=286*. For more information about the "two motors" hypothesis, see "The kinetics of root gravitropism: Dual motors and sensors" (C. Wolverton, H. Ishikawa, and M. L. Evans, *Journal of Plant Growth Regulation*, 21, 102–112, 2002). For an in-depth discussion of the fluorescent protein studies, see "Gravity-regulated differential auxin transport from columella to lateral root cap cells" (I. Ottenschläger, P. Wolff, C. Wolverton, R. P. Bhalerao, G. Sandberg, H. Ishikawa, M. Evans, and K. Palme, *Proceedings of the National Academy of Sciences of the United States of America*, 100, 2987–2991, 2002).

From Liquid to Solid to... _continued from page 17_

direction and the other across. ISS Science Officer Don Pettit then ran nine 1- to 2-hour pulsed power tests on each of the vials, using continuous power to freeze the structures and record the results.

"We expected to see fishlike structures floating around in three dimensions," says Gast. Instead, she observed columns or two-dimensional sheets that folded and fluctuated. "If you're oriented with the magnetic field and look down on those sheets from north to south, you'll see a labyrinth, a maze structure," she explains. "If you look across from east to west, they look opaque."

Gast has not yet fully characterized the structures, and she is clearly wary of speculation. "We haven't evaluated the data well enough to determine if the sheets are interconnected. We believe they are mostly separated, but folded so they're wound with one another. They fluctuate and wiggle and can take a random walk." Yet she underscores that the results were entirely unanticipated. They suggest that amid the competition of interfacial, magnetic, and gravitational forces, the latter play a critical role in the formation of ellipsoidal structures.

The results also accentuate how little is understood about the fundamental properties of MR fluids. With each advance, however, comes the possibility of new breakthroughs that will make future MR devices more reliable, stronger, and less power intensive.

Gast and other developers in the field envision a bright future for MR systems. One day, a surgeon may strap on a glove containing capillaries filled with MR fluid. Thousands of miles away, a robotic arm arrayed with pressure sensors will hold a scalpel. As the surgeon views a virtual image of the patient and begins the remote procedure, the fluids in the glove will stiffen and relax, replicating the resistance a human hand would feel as it cuts and stitches during surgery. To the surgeon, it will feel as if the patient is lying on the table below.

No one will be thinking about space. But the users of future MR systems may have today's microgravity researchers to thank for the systems' reliability.

Alan S. Brown

Detailed information about InSPACE, Gast's investigation of MR fluids conducted on the ISS, is available at *http://microgravity.grc.nasa.gov/inspace/overview.html*.
To view a list of selected publications, visit Gast's MIT faculty web site at *http://web.mit.edu/cheme/people/faculty/gast.pubs.html*. Gast also was profiled in the March 2002 issue of *Space Research*, available at *http://spaceresearch.nasa.gov/general_info/spaceresearchnews.html*.
Descriptions of MR fluid applications can be found on Lord Corporation's MR fluid home page, *http://www.rheonetic.com*, and in an article titled "Amazing Magnetic Fluids" at *http://science.nasa.gov/headlines/ y2003/02apr%5Frobotblood.html*.

Secrets of Cell Growth _continued from page 19_

disease that can be used in the development of new drugs and vaccines.

The metabolite generator uses the bioreactor to create functional tissuelike cultures of differentiated cells (derived from liver, kidney, or other tissue) that yield biochemical products. Kidney cells produce unique hormones such as vitamin D3 and erythropoietin. (Vitamin D3 regulates calcium levels, and supplementation is important for patients with kidney damage, who don't produce enough of it themselves. Erythropoietin helps regulate red blood cell production, and levels that are too high or too low can cause anemia.) Liver cells produce important blood proteins such as albumin, globulins, and clotting factors as well as metabolites, biochemical byproducts that can be useful as pharmaceuticals or for the study of drug efficacy and toxicity.

StelSys' liver-assist device would work something like a kidney dialysis machine. A patient's blood would flow externally through the device for treatment by the cultured liver cells. The device would be used to prolong the survival of patients with liver failure until a liver transplant could be performed.

Hammond's space research should provide important information to help StelSys with its goals. Knowing which genes trigger vitamin D3 and erythropoietin production in microgravity will help the biotech company grow kidney cells that produce the hormones in the bioreactor. And learning which genes contribute to a cell's survival in orbit may enable StelSys to sustain liver cells grown in vitro long enough to stand in for a failed liver.

credit: NASA

Astronaut Terrence Wilcutt, mission commander during space shuttle mission STS-106, conducts a daily status check on BioServe's Commercial Generic Bioprocessing Apparatus payload containing Principal Investigator Tim Hammond's kidney cell experiment.

Carolyn Carter Snare

For more information about Hammond's research, see *http://www.mcl.tulane.edu/astrobiology/*. For more information about StelSys, see *http://www.stelsysllc.com/*. For more information about BioServe, see *http://www.colorado.edu/engineering/BioServe/*.

Profile: Clarence Sams

Even though his love of flying led him to the sky at an early age, researcher Clarence Sams chose a career in biochemistry over aviation. Now his research into the effects of spaceflight on biological systems enables him to enjoy both worlds every day.

The open sky is a siren song that calls many to a career in flight. Piloting an aircraft demands reliance on one's own abilities and training, knowing that one's own life depends on making the right decisions in response to weather, aircraft conditions, and myriad other details — any one of which could change without a moment's notice. Only those people who can make sound judgments quickly, take risks willingly, and adapt to changes in conditions easily get to soar above the clouds under their own guidance.

Clarence Sams, biochemist and manager of the Cell and Molecular Research Laboratory at NASA Johnson Space Center, Houston, Texas, grew up in a family of aviators in Oklahoma. He learned to fly at an early age and planned on following his father into aviation and becoming a professional pilot. But his interest in scientific exploration called to him as well, and the skills he had developed as a pilot — sound judgment, flexibility of mind, and the willingness to take risks — could serve him admirably as a researcher. Through his biochemical research for the space program, Sams is able to combine his interests and have the best of both worlds.

"I've always been interested in science, in one way or another," explains Sams. He was inspired by his high school chemistry teacher, "a very rigorous fellow … with an incredible presence" who had been an industrial chemist. While working in industry, this fellow had observed that the young chemists entering the workforce were not adequately prepared for their jobs. So, he quit his job and became a teacher, doing what he could to better prepare the next generation of scientists. Sams worked with this teacher as a lab assistant before heading to Rice University, where he enrolled as a chemical engineering major.

One of Sams' strongest piloting skills is his flexibility of mind — his ability to change directions in response to changes in conditions. Once at Rice, Sams realized that "from the work standpoint, [chemical engineering] wasn't the career that I wanted, and I became interested in organic chemistry and biochemistry. I thought the application of chemistry to life systems was very interesting." He changed majors and went on to earn his bachelor's degree in biochemistry.

After receiving his degree, Sams returned to his first love — flying — and went to work as a copilot in business aviation. However, the aviation industry was in a slump; pilots were being laid off, not hired. So, he reassessed his career plans and decided to go back to college for a doctorate in biochemistry.

The day Sams turned in his doctoral dissertation, he made the decision that would eventually bring him to NASA. On a bulletin board near the biochemistry department office was a notice announcing the National Research Council's Resident Research Associateships at NASA. Demonstrating another of the skills he learned as a pilot — the willingness to take a risk and explore new territory — he applied for and was granted a research fellowship at Johnson Space Center.

Sams' fellowship lasted from 1984 to 1986, and in 1987, NASA hired him as a research biochemist. Since then, his research has centered on the biological effects of spaceflight at the cellular and subcellular levels. Currently, his research focus is on how immune cells are affected by spaceflight. The immune system acts as a protective shield, blocking harmful microbes and toxins from invading the body and attacking any that manage to get into the body through a wound or another injury. Any malfunction of the immune system in astronauts is cause for serious concern, especially during long-term spaceflight. By better understanding how the immune system reacts to similar stresses on the ground, scientists can develop countermeasures to reduce or eliminate these effects during spaceflight.

Flying and scientific research both demand a large degree of skill, dedication, and commitment. They are not fields for people who like to work from 9 to 5. But they also give an equally large return on investment. "Most pilots fly because they love to fly," Sams observes. "The good ones are always learning. I think that's one of the other joys of this job [research]: you have to keep learning, challenging yourself, and trying to figure out something new. That's part of the professionalism that pilots have, and it's part of the process of doing science. So that's the common ground between those two fields."

credit: Unknown

Therein lies the secret to Sams' success and his nature: science is both a challenge and a delight. It challenges his intelligence and ability to think outside of the box — or in his case, beyond Earth's gravity. It delights his sense of adventure, perhaps even as much as flying. And he is not alone in feeling this way. "The other thing that I really do enjoy about my job is the fact that I have a lot of like-minded people around me," he explains. "I get to work with really intelligent, dedicated, interested, and interesting people. It's an intriguing and fascinating team."

Carolyn Carter Snare

Contact Clarence Sams via e-mail at *Clarence.sams-1@nasa.gov*. For more information about his research, visit *http://haco.jsc.nasa.gov/biomedical/molecular.shtml*.

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